Surveying for archaeologists

Sir Norman Lockyer

SURVEYING
FOR ARCHÆOLOGISTS

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SURVEYING FOR ARCHÆOLOGISTS

BY

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"Druides . . . multa praeterea de sideribus et eorum motu, de mundi magnitudine, de rerum natura, de deorum immortalium vi ac potestate disputant et juventuti tradunt."
—*Caes. De Bello Gallico*, VI., c. 14.

"Hi terrae mundique magnitudinem et formam, motus coeli ac siderum, et quid Dii velint, scire profitentur."
—*Pomp. Mel. De Situ Orbis*, III., c. 2.

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PREFACE

In the following pages no attempt has been made to write a complete treatise, but rather to deal with the fundamental points on which, as I know, many archæologists who are now taking up the study of the orientation of ancient British monuments are seeking information.

The archæologist must not imagine that a complete grasp of all the computation methods referred to is necessary before he commences operations; good work can be done by collecting the data required by means of simple instruments, leaving the subsequent calculations to others.

I have thought it desirable to say more about the astronomical conditions involved than is generally to be found in elementary treatises on surveying for the reason that the changes in the position of the sun and stars from century to century are involved in the new inquiries.

Although this work is chiefly concerned with British monuments, I have added a final chapter showing how the methods and principles involved in the measures of alignments can be applied, for the purpose of preliminary inquiries, in other latitudes. There are now several schools of Archæology and other organisations interested in ancient sites and monuments away from home. I firmly believe that when they add the exact study of the orientation of temples and palaces to their other inquiries, important information as to building dates will be secured.

My best thanks are due to my son, Captain H. C. Lockyer,

R.N., formerly of the Surveying Department of the Navy, for looking over the chapters dealing with methods of work, and to Mr. Rolston, of the Solar Physics Observatory, for the preparation of the tables of azimuths which are given in the concluding chapters, and for general assistance and proof reading.

My thanks are also due to Messrs. Macmillan for the use of some of the illustrations which have appeared in *Nature*, and to Messrs. Stanley, Negretti and Zambra, and Verschoyle who have been good enough to lend blocks of some of the simpler surveying instruments.

NORMAN LOCKYER.

SOLAR PHYSICS OBSERVATORY,
May, 1909.

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SURVEYING FOR ARCHÆOLOGISTS

CHAPTER I

INTRODUCTORY

We have now two societies for the astronomical study of ancient monuments at work in Britain; a considerable number of the monuments has already been astronomically surveyed, with the result that it has been demonstrated that the various alignments indicated were laid out to facilitate and utilise observations of the sun and stars.

It is not to be wondered at, therefore, that I have been repeatedly asked, now in one region, now in another, to put on paper some general hints to those who may feel inclined to take up the work so as to secure the necessary observations.

I think the first useful thing to say is that the inquiry is much less complex, and takes much less time in the measurement of any one monument, than is generally imagined; that the ideas involved are very simple, and do not go beyond the knowledge which should be possessed by everybody who wishes to enjoy and understand something of the world around him.

In the first place, the astronomical side of the inquiry, so far as the monuments are concerned, is very restricted. It has little to do with the various data concerning them which archæologists, with wonderful diligence, have now been accumulating for several centuries. The weight, shapes, size, colour and nature of the stones are not in question. All use of the spade for finding treasure or anything else is not in our province. If, when plans are given, the relation of the stones to each other is accurately given, we can accept them so far as the arrangement of the stones *inter se* is concerned.

One great advantage of being freed from the necessity of doing all this work is that would-be inquirers are saved the expenditure of a great deal of time and money; to them the spade is needless, because they deal only with the relation of the monument to the surrounding surface, and for the same reason the conditions of the stones themselves are indifferent to them.

What, then, is it that they have to do? They have simply to determine, with an accuracy as great as can be achieved by the instruments at their disposal, the line of direction indicated by the lie of the stones in the various monuments. This problem is at its simplest in the case of the so-called "Avenues," such as those at Challacombe and Merrivale, on Dartmoor.

Do they lie east and west, or north and south, or in any other intermediate direction?

Again, take the cases of the so-called "outstanding" stones or tumuli so often met with at some distance outside the Cornish circles—those of the Merry Maidens and Tregaseal, to give instances. Do they lie to the east, or the west, or the north or the south, or at some intermediate angle? and at what angle?

In the case of cromlechs or dolmens the matter is not quite so simple, except in the case of those furnished with an obvious outlook, an *allée ouverte* or *couverte*, to adopt the terms employed by French archæologists. I suppose there are hundreds of monuments of this class, of which so-called "plans" exist, but in spite of these plans, which may be quite good so far as the interrelation of the stones is concerned, we have no certain knowledge as to the exact direction in which these alley-ways or creeps point. The stones have been dealt with as stones, and their relations to their surroundings have been entirely neglected. Fundamentally, then, to get out of this *impasse* it is a question of obtaining the facts regarding these directions in the first instance.

How is this to be done? It is here that the elements of knowledge of the things around us, which, I am thankful to say, now form part of the teaching in our best elementary schools, and which, therefore, are not of a very recondite nature, come in.

The ancient monuments, like everything else on the face of the earth or sea, appear to anyone who examines them close at hand

to occupy the centre of a plane, which is really the little bit of the surface of the earth that we can see from any one point of view. This circular patch of land or sea is bounded in every direction by what is called the *horizon*, which is the most distant part of the land or sea from us on which the sky seems to rest. In the case of the sea, this horizon is level all round. In the case of the land, it may be high or low according to the surrounding conditions. If we live in a street the horizon is high, its height depending upon the number of storeys in the opposite houses; if we are on the heights of Dartmoor it is very low, almost as low as a sea horizon, and as sensibly circular.

Suppose us, then, in front of an avenue, surrounded by this circular horizon; how, when we have measured the stones and plotted them at the proper distances apart, can we indicate the general direction of the lines of stones? We can divide the circle of the horizon, like all other circles, into 360°; but where—in what direction—are we to begin the numbering? Where must the zero be?

All mankind has now agreed for hundreds of years that the zero must be the *north* point; opposite to it is the south point, and the line joining these north and south points is called a *meridian line.*

This meridian line, passing along the earth's surface and joining the north and south points of the horizon, lies in a vertical plane passing through the point overhead called the *zenith.* The term meridian is used because the sun passes through this plane at the middle of each day. The line at right angles to the meridian line passes through two points on the horizon midway between north and south. These are called the east and west points, and in the four points now named we have the so-called *cardinal* points of the horizon.

The meridian so defined is called the *astronomical meridian,* and the cardinal points of the horizon involved are called astronomical or true.

The *astronomical* north and all the other points are absolutely stable; they never vary, and are always the same at all places. This north point may be roughly found at night, as it is the point of the horizon under the pole-star, the star which nearly occupies the centre of the circle round which the stars revolve in their

daily apparent movement. The south point may be defined as the point of the horizon under the sun at noon.

Now all this seems plain sailing, but the trouble of it is that there are two north points and two meridians to be considered.

If we take a magnetic needle and balance it horizontally on a vertical pivot, its ends will be directed to two points on the horizon, which are not the same at all places with regard to the cardinal points. By drawing a great circle through these two points and the zenith point of the place, we obtain the plane of the *magnetic meridian.* The magnetic needle, as we see it in a pocket compass, has a marked N. end, and its length lies in and defines the magnetic meridian.

The *magnetic meridian line* is the intersection of the plane of the magnetic meridian with the plane of the horizon.

In Britain these two meridians do not coincide; at present, on the average, they form an angle with each other of some 18°, so that the magnetic north is 18° to the west of the true north.

The angle between the astronomical and magnetic meridian lines is called the magnetic *variation,* east or west according as the north end of the needle points to the west or east of true—that is astronomical—north at any particular place at any particular time.

Such a needle is never at rest, as it is for ever under the influence of the magnetism of the earth, which is always varying. The north point it indicates, therefore, *varies* from year to year; hence the term *variation*; it also greatly varies from place to place, so that there is nothing stable about it; another difficulty is, there may be a local magnetic attraction, caused by iron in the underlying strata, or even gas or water pipes or iron railings, which interferes with the general magnetic attraction at the place, so that a reference to a *general* chart is insufficient.

In a survey of any kind, whether of stone monuments or houses and trees on an estate, to take instances, the first desideratum is a point of reference to which all measures must be referred; but the plan as a plan is incomplete unless the relation of the point of reference used to the astronomical north, or the magnetic north, point of the horizon is quite accurately shown.

Now, the reason that so many archæologists have dealt with the

magnetic meridian and the magnetic north is that it is much more easy to determine them. Unfortunately, it has not struck them that their measures of angles, *so far as direction is concerned*, are useless unless the relation of the magnetic meridian to the astronomical meridian, at the monument under investigation and at the time of measurement, has been accurately determined.

It must be confessed that there is much excuse for them, for, until a few years ago, it was difficult in the absence of magnetic surveys to obtain this relation, which consists in an accurate statement of the angle called, as we have seen, the *variation* between the magnetic and astronomical meridians, or, in other words, the angle between the magnetic and astronomical north points of the horizon.

To give a concrete case of the facts, let us consider the case of the Nile Valley, where work such as we are now considering was begun by a Commission of the French Academy of Sciences in 1798.

They found that in 1798 a magnet swung along a line extending from a little to the west of Cairo to the second cataract had a variation of 11½° to the west. In 1844, when the great Lepsius, the prince of archæological surveyors, arrived on the scene to prepare his majestic plans of the temples he found the west variation no longer 11½°, but 8½°. At the present time the variation is nearer 4° west. But, alas! in the modern British Schools and Institutes of archæology little attention is given, to judge from the data shown in the plans they publish, to the question which we are now considering. A notable proof of this may be gathered from the fact that, in spite of all the statements and plans that have been made lately concerning the newly explored temple at Deir-el-Bahari, I have been unable to learn whether the indicated direction of the axis of the temple is magnetic or true; the only information given me, oh! shade of Lepsius! is that the variation had not been determined by the surveyors.

It will be gathered from the above that when we may have to deal with such a large change of the variation in a century, an old plan with magnetic bearings but without the date of the actual observations is worse than useless. Even when the date is given, a reference to old Admiralty charts is necessary to get even

an approximation to the value of the variation. This is one objection to the use of the magnetic meridian.

But, whatever has happened in the past, for the future British archæologists can hardly be excused from neglecting to compare the magnetic meridian they may use for their plotting with the true or astronomical meridian, and stating it on their plans.

Both the Admiralty and the Ordnance Survey have lately been busily employed in determining the magnetic variation over the British Isles, and in future it will be shown on every 1-inch Ordnance map, so that every archæologist, for the expenditure of one shilling, will be able to learn the present variation at any monument he may chance to be surveying. Indeed, it may be said that some of the old difficulties are now in a large measure solved.

The Admiralty have recently prepared a map showing this variation for the British Isles for the year 1907, from which archæologists can learn approximately the value of the variation, and hence the direction of the true north, at any place.

But because most of the difficulties connected with the observations of magnetic bearings are disappearing, it is certain that the magnetic method will still continue to be largely employed, as it is the easier to work with.

It is not too early to emphasise the important fact that for the *astronomical* study of the various directions, we want, for a reason I shall state later on, more than the angle from the north point, either magnetic or astronomical, generally termed the *azimuth*. We want the angular height of the horizon where the line of direction cuts it. This is called the *altitude*.

CHAPTER II

HOW AZIMUTH AND ALTITUDE ARE DEFINED AND READ

Azimuths.

A REFERENCE to the transactions of antiquarian societies will show that in the past the most commonly employed method of stating direction, or azimuth, has been by using a compass needle, armed with a card such as is used by mariners, and hence called a mariner's compass. This, of course, gives us magnetic bearings.

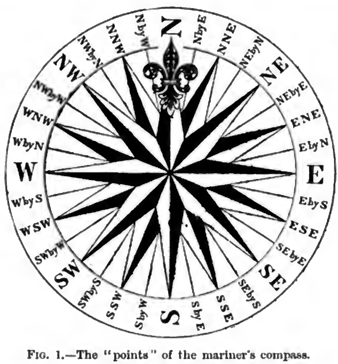


FIG. 1.—The "points" of the mariner's compass.

In this the circle is divided into thirty-two parts, called points: four chief magnetic points, N., S., E., W.; four quadrantal points, N.E., S.E., S.W., and N.W.; and twenty-four intermediate points. If we take the N.E. quadrant, for example, the eight defining

points are N., N. by E., N.N.E., N.E. by N., N.E., N.E. by E., E.N.E., E. by N. Now as these thirty-two points cover the 360° in the complete circle, each point contains 11° 15′, so that, reckoning directions in this way, there is a play of more than 10° for each statement made.

But the objection to this method of defining does not end here. If we read the bare statement that a cromlech, to take an instance, is open, say, to the N.E., one is apt to think that the true N.E. is intended; but where the variation is about 22°, as it

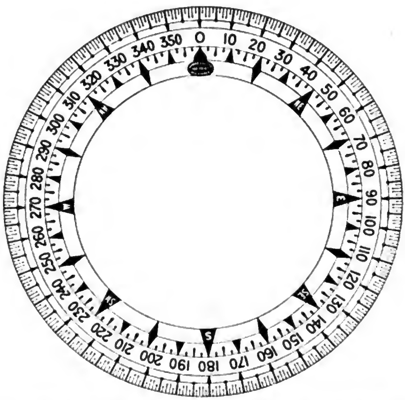


FIG. 2.—Compass card with the circle of the horizon divided into 360 degrees, the N. point being 0°.

is now in the west of Ireland, true N.E. is N.N.E. by compass, that is, two points more westerly.

This system of reckoning, then, besides being misleading, is too coarse for our purpose, so much so that even mariners are now giving it up, using degrees instead of points, and there are now mariner's compasses available in which the bearings are stated in degrees, and in many ways, the degrees running from N. and S. to E. and W., and so on. The best form of card, however, is one in which the degrees run from N. through E., S., W. to N. again.

This card has long been used in the Admiralty Surveying ships. A convenient design shown in Fig. 2 has recently been registered by Mr. Collins.

On this system each magnetic bearing is defined quite independently of any quadrant, so mag. east would read 90°, and mag. west 270°.

The circles of small instruments are graduated to degrees, and so the azimuths are read to degrees and estimated to half degrees. In instruments with larger circles, whether it be a circular protractor for reading azimuths on maps, or a theodolite for determining them, the degree can be read to $\frac{1}{10}$th of a degree, or even more finely, by means of a device called a vernier, on which it is useful to dwell a little, as many regard it as of a recondite and mysterious nature and avoid it accordingly, whereas it is as simple as it is useful.

The vernier is a short scale, constructed so that its divisions are smaller by a definite and convenient amount than those of the

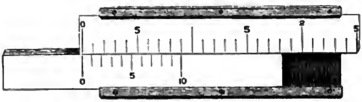


Fig. 3.—Model of a vernier showing how the divisions on a straight line can be divided into tenths. Here the vernier (below) has its zero point coincident with a division on the scale.

scale with which it is used. In a very simple case this difference amounts to $\frac{1}{10}$th of a scale division, and the vernier is made so that its ten divisions are equal in length to nine on the primary

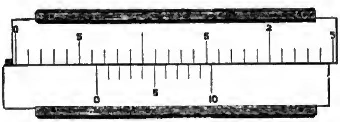


Fig. 4.—Here the zero of the vernier is between the 6th and 7th divisions of the scale: The third division of the vernier is coincident with a division of the line, so the reading is $6\frac{3}{10}$.

scale. One extremity of the vernier scale is the reference point or zero, and if this be coincident with a scale division, the remain-

ing divisions of the vernier will be separated from divisions of the scale as indicated below :—

Division	0	of vernier	coincident with zero division of scale		
,,	1	,,	falls $\frac{1}{10}$th short of next division of scale.		
,,	2	,,	,, $\frac{2}{10}$ths	,,	,,
,,	3	,,	,, $\frac{3}{10}$ths	,,	,,
,,	4	,,	,, $\frac{4}{10}$ths	,,	,,
,,	5	,,	,, $\frac{5}{10}$ths	,,	,,
,,	6	,,	,, $\frac{6}{10}$ths	,,	,,
,,	7	,,	,, $\frac{7}{10}$ths	,,	,,
,,	8	,,	,, $\frac{8}{10}$ths	,,	,,
,,	9	,,	,, $\frac{9}{10}$ths	,,	,,
,,	10	,,	is coincident with		,,

If then the vernier be in such a position in relation to the scale that its fourth division is coincident with a scale division, the zero

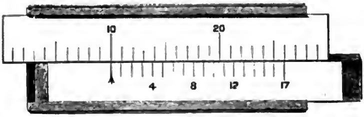


FIG. 5.—If, instead of measuring tenths of a division, we wish to measure seventeenths, we make a vernier in which 17 divisions take up the same length as 16 divisions of the scale, we then slide the vernier along and note the coincidence of the lines.

mark must be $\frac{4}{10}$ths removed from a scale division, and so on. In this way the coincidence of the vernier and scale divisions indicates the fractional part to be read.

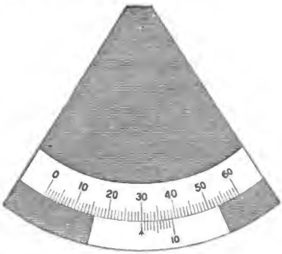


FIG. 6.—A vernier applied to a circle enabling azimuths (or any other angle) to be read to tenths of a degree.

It is quite easy to make a wooden model of a fixed scale and a sliding vernier; a little manipulation of this will make everything quite clear

In a circle graduated to half degrees, the vernier is so constructed that its thirty divisions are equal in length to 29 divisions of the circle. The vernier divisions are therefore smaller than those of the circle by

$$\frac{1}{30} \times 30' = 1'$$

and the vernier is said to read to one minute. Thus to set the index of the vernier at the reading 30° 18′, first adjust it to the position 30°; then move the index towards the mark corresponding to 31°, and stop when the eighteenth division of the vernier becomes coincident with a division of the scale.

So much, then, for the reckoning and readings of azimuth measurements on a horizontal plane.

Altitudes.

For the reckoning of altitudes, which of course are observed with a vertical circle, the degree system is alone used, the fineness of the reading depending upon the size and graduation of the circle employed. The vertical circle is generally graduated into four quadrants of 90°, the zeros lying in the horizontal line. We can thus read elevations or depressions in degrees, or some smaller division of a degree, according to the vernier used.

CHAPTER III

CONCERNING HORIZONS

So long as we are dealing with measurements of azimuth on the horizon, and altitude above the horizon, we are considering only our position on the earth—on that part of it which is bounded by our horizon. We are not dealing with the true position in the heavens of any body, whether sun or star, which may rise or set in the directions defined by our measures.

We are only dealing, in fact, with what is termed the *sphere of observation.*

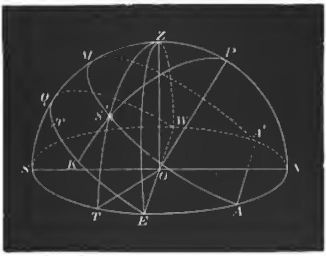


FIG. 7.—The sphere of observation. O, the position of an observer at the centre of the sphere, surrounded by the horizon; N. E. S. W. (the true cardinal points), with Z, the zenith, the point over the observer's head. The line N. S. is the true meridian line. The plane bounded by the line N. E. S. W. is the plane of the horizon, or the horizontal plane. The line O Z, a *vertical* line, is at right angles to the plane of the horizon. The plane E O W Z is the prime vertical, that is, a plane at right angles to the meridian.

The figure will illustrate what has already been said about azimuth, and will enable us to define some new technical terms which will be used later on. For *true* azimuths the zero is at N., which represents the N. point of the horizon, so that the azimuth

of the E. point is 90°, of the S. point 180°, of the W. point 270°. Next let us take some intermediate points, A and T. The arc NA is the azimuth of A, the arc NT the azimuth of T. Sometimes it is convenient to define the position of a point on the horizon, not from the N. point (*azimuth*), but from the E. or W. point; we speak of this measure as *amplitude*. In any quadrant the one is the complement of the other, that is, added together, they make 90°.

The points A, T, like the points N. E. S. W., are represented as being on the horizon, so the distances of all these points from Z, called the *zenith distance*, are the same. If we represented these points not *on*, but *above* or *below* the horizontal plane, it is obvious that the zenith distances would not be the same. The higher the point is above the true horizon, as would happen if there were a hill there, the less the zenith distance.

The circle which we actually observe all round us where the heavens seem to rest on the surface which we see, is termed the *visible horizon*. We imagine a plane parallel to the plane of the visible horizon, but passing through the centre of the earth; this is called the *rational* or *true* plane of the horizon.

So much for the horizon as a part of the earth's surface.

In the astronomical survey of ancient monuments, the determination of the azimuth of the various sight-lines, and the altitude of that part of the horizon which bounds them, is for the purpose of studying the sight-lines in relation to the rising or setting places of sun or star.

What we have to do, therefore, is to study the relation of the sphere of observation to what is called *the celestial sphere*, the sphere on which in old time the stars were supposed to be fixed like golden nails.

To do this we must pass from the consideration of the sphere of observation at any place to a study of the earth as a whole, and its movements, or at all events of some of them.

We have the earth in space with the universe of stars, almost infinitely removed, all round it, and we now know that the apparent movements of the stars from east to west, their daily risings, passing over the meridian and settings, in the sphere of observation at any place, are only the reflections of the earth's daily movement, or spin, on its axis from west to east.

The points at which this axis cuts the earth's surface are called the N. and S. poles, and half-way between these the earth is bounded by a circle called the *equator*. Now, as the daily motion of the earth is reflected in the apparent daily motion of the stars, so is the system of defining positions on the earth reflected in the

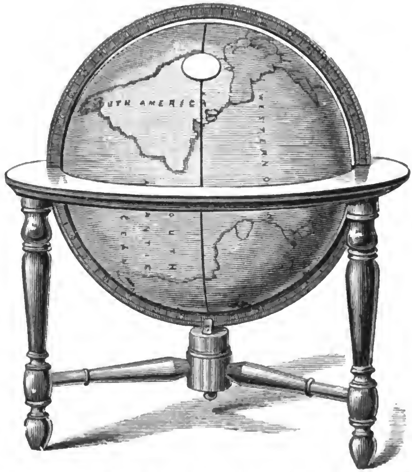


FIG. 8.—A model of the earth, showing that when the poles lie in the plane of the true horizon, and therefore of the wooden horizon which represents it, the horizon, represented by a wafer, of an observer situated on the equator, is carried vertically up and down by the earth's rotation: this motion reflected causes the apparent up-and-down motion of the stars as observed at the equator.

system employed by astronomers in defining positions in the heavens.

As the earth is belted by *parallels of latitude* and *meridians of longitude,* so are the heavens belted to the astronomer with *parallels of declination* and *meridians of right ascension.* If we suppose the plane in which our equator lies extended to the stars, it will pass through all those which have no declination (0°). Above and below we have north and south declination, as on the earth's surface we have north and south latitude, until we reach the poles of the equator (90°). As on the earth we start from the

meridian of Greenwich in the measure of *longitude*, so do we start from a certain point in the celestial equator occupied by the sun at the vernal equinox, called the *first point of Aries*, in the measure of *right ascension*.

So that we have terrestrial *latitude*, reckoned from the terrestrial

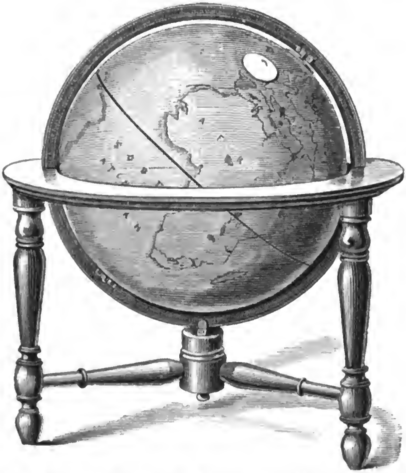


FIG. 9.—In this case the axis is inclined to the wooden horizon, which is parallel to the horizon of Britain when at the top of the globe. The wafer representing the horizon of Stonehenge is carried obliquely up and down in a direction parallel to the equator, so that the sun and stars rise obliquely to the horizon.

equator, corresponding with celestial *declination*, reckoned from the celestial equator, and terrestrial *longitude* corresponding with right ascension.

It is the *declination*, that is, the distance from the celestial equator, with which archæologists chiefly have to deal, for the reason that the rising and setting places of celestial bodies depend upon their declination; *bodies with the same declination rise and set in the same azimuths.*

Now the presentation of the plane of the horizon of a place to the surrounding stars which together constitute the celestial

sphere varies vastly with its position on the earth's surface. Whether stars rise and set at all, or if they do whether they rise and set vertically or obliquely, depends upon this position, or, to be more precise, upon the latitude of the position. It is a pity that "calisthenics and the use of the globes" no longer form part of a liberal education, for a study of a terrestrial globe, which is a model of the earth in relation to the celestial sphere, gives us help in the matters we are now considering.

Such a globe is furnished with a wooden horizon, which represents the true or rational horizon passing through the centre of the earth as before defined. The axis of the globe prolonged is fixed into a brass ring representing the meridian, and the axis can be inclined at any angle in regard to the wooden horizon.

Now, wherever the archæologist is working, his observing place, bounded by his horizon, appears to lie at the top of the earth, and therefore parallel to the wooden horizon; let us therefore use two wafers to represent local horizons, and place one on the equator and the second on Britain.

When we bring the equatorial wafer to the top of the globe, where it lies parallel to the wooden horizon, we find that on rotating the globe it sweeps down in a vertical plane. The wafer over Britain, parallel to the wooden horizon when it is brought to the top of the globe, when the globe is rotated, takes an *inclined* path to the horizon. This happens because the axis, instead of lying in the plane of the wooden horizon, is inclined to it. This inclination of the axis varies with the latitude of the place, and so the angle of inclination of the path of the wafer to the wooden horizon varies with the latitude. If we so arrange our model earth that the inclination of the axis is the greatest possible, and the earth's equatorial plane lies in the plane of the wooden horizon, it is obvious that the earth's movement will only cause a wafer at the pole to rotate; with this exception it will remain at rest, and as there is no vertical motion to reflect, the stars will neither rise nor set.

Now the value of these little experiments depends upon the already stated fact that the *apparent* movements of the heavenly bodies are brought about by the real movements of the earth, and the experiments show us that in regard to the horizon at any place

the *true* movement of the underlying earth, and therefore the *apparent* movement of the overlying heavens, is vastly different.

At the equator an observer's horizon is being whirled round in a vertical plane at the rate of 1000 miles an hour; at the poles the horizon remains parallel to itself. In Britain we have a

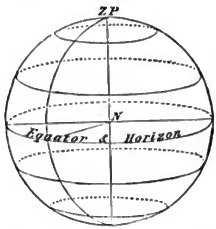


FIG. 10.—The conditions of the celestial sphere at the North Pole. *N*, observer; *ZP*, the pole in the observer's zenith. Only half the stars are above the horizon, and they neither rise nor set, but appear to move parallel to the horizon

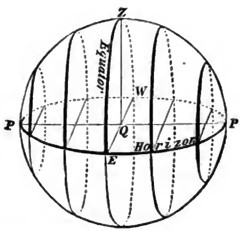


FIG. 11.—The conditions of the celestial sphere at the equator. *P*, *P*, poles on the horizon; *Q*, observer with the equator in his zenith, *Z*. All stars rise and set, and their apparent paths all cut the horizon.

midway condition. Correspondingly with these differences, at the equator we have stars rising and setting vertically and rapidly; in Britain stars rising and setting obliquely and more slowly; at the poles the stars neither rise nor set.

The globe experiments also show us that the conditions of the so-called "sphere of observation" at the poles and equator vary most from each other.

In Fig. 12 *D*, *D′* shows the apparent path of a circumpolar star, that is, of a star whose complete journey round the pole is performed above the horizon; *B*, *B′*, *B″*, the path and rising and setting points of an equatorial star; *C*, *C′*, *C″* and *A*, *A′*, *A″* those of stars of mid-declination, one north and the other south.

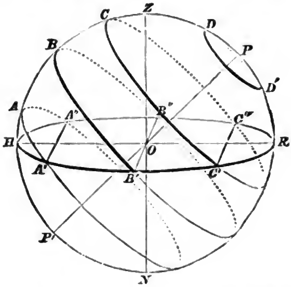


FIG. 12.—The conditions of the celestial sphere in a middle north latitude (Britain). *O*, observer; *P*, *P′*, poles. Here some stars do not set—that is, their path does not reach the horizon *H*, *A*, *B*, *C*, *R*. Others do not rise, and all move obliquely with regard to the plane of the horizon.

In middle latitudes, and therefore in Britain, we may divide the stars into three classes:—

I. Those northern stars which never set (northern circumpolar stars).

II. Those southern stars which never rise (southern circumpolar stars).

III. Those stars which both rise and set.

It is easily gathered from Figs. 10 and 11 that the height of the celestial pole above the horizon at any place is equal to the latitude of that place; for at the pole in lat. 90° it was in the zenith, and its altitude was consequently 90°; at the equator, in lat. 0°, the pole was on the horizon, and consequently its altitude was 0°; while in lat. 45° its altitude is 45°. In London, therefore, in lat. 51½° its altitude will be 51½°, and hence stars of less than that distance from the pole will always be visible, as they will be above the horizon when passing below the pole. All the stars,

therefore, within 51° of the north pole will form Class I.; all those within 51° of the south pole Class II.; and the remainder—that is, all stars from declination 39° N. (90° − 51° = 39°) to 39° S.—will form Class III.

We may now return for a moment to Fig. 7, which we have so far considered in relation to the sphere of observation. It really enables us to study as well the conditions of the celestial sphere for the horizon N. E. S. W. of, let us say, Stonehenge in lat. 51° N. P represents the position of the celestial pole, and EQW the inclination to the horizon of the celestial equator for that latitude. The lines EQ and AS′M give the angle of slant as the sun or a star on the equator or in a northern declination rises above the horizon.

Two or three technical terms which will be often used afterwards may here again be referred to. PN gives the height of the celestial pole, which is the same as the latitude of the place, ZP its *zenith distance*; it will be seen that these are complementary to each other, that is, together they make up 90°. S′ representing a star or the sun, PS′ is its *polar distance*, as KS′ is its *declination* or distance from the equator; it is seen that these again are complementary to each other. The line S′Z represents its zenith distance.

CHAPTER IV

INSTRUMENTS FOR THE MEASUREMENT OF MAGNETIC AZIMUTH ALONE.

THE most inefficient instrument to employ in measuring magnetic bearings is the ordinary mariner's compass, showing the compass points only. But whatever kind of compass or card is used, the magnetic bearings thus obtained should at once be changed into true bearings; this can be done approximately by reference to the appended maps, which bring together the recent results obtained by the Admiralty. The full smoothed line shows the average position of the line of equal variation for 1907, the dotted line the variation obtained from land observations alone, and the dot and circle line that got by observations at sea alone.

It will be seen that there is a slight divergence between the land and sea observations, but in spite of this the chart enables us to estimate the variation at any place on it within half a degree without astronomical observation.

As the magnetic azimuths run through N.E.S.W., and the magnetic variation in the British Isles is *west*, it follows that, to obtain the *true* azimuth the value of the variation should always be *subtracted* from the magnetic reading. I am glad to learn that the use of the mariner's compass pure and simple is now rapidly going out of use so far as archæologists are concerned, and for the rapid measurements of azimuths alone, using magnetic bearings, the azimuth, or prismatic, compass invented by Captain Kater about 1814 is the instrument generally employed.

It is cheap, light and handy. In the smaller instruments the needle is attached to the under surface of a compass card showing the thirty-two points of the compass. In the best forms, with

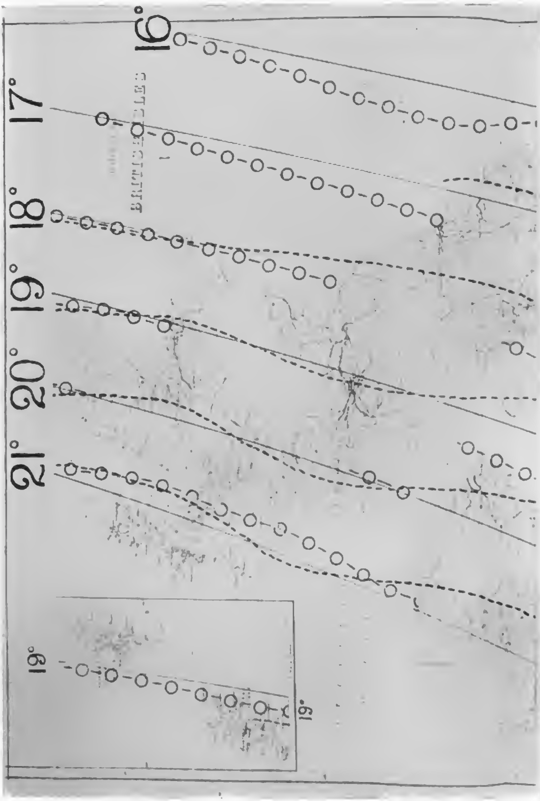


Fig. 13.—The western magnetic variation in N. Britain and N. Ireland in 1907.

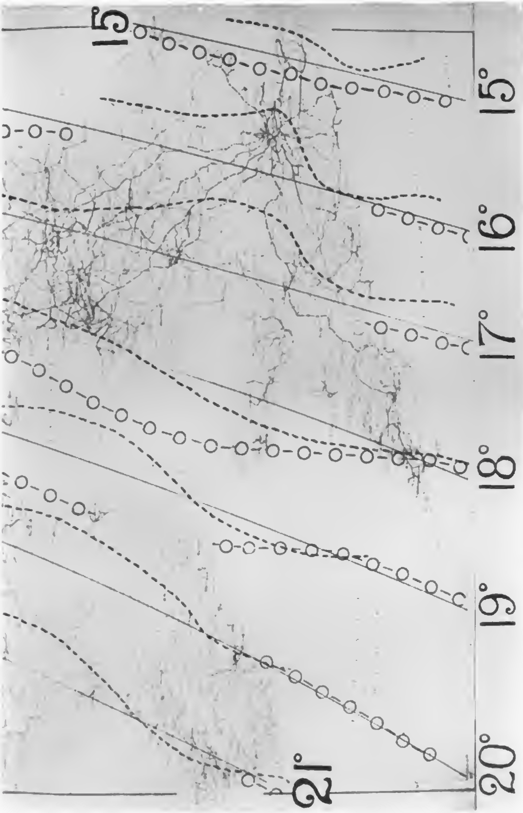


FIG. 14.—The western magnetic variation in S. Britain and in S. Ireland in 1907.

a diameter of 6 inches, a magnetised bar, having an agate centre balanced on a steel pivot, carries an aluminium ring, which is graduated to degrees; and with many monuments a greater accuracy than this is not possible. Its general arrangement will be gathered from Fig. 15. At one end of the box is a fine wire, at the other a right-angled prism; above the prism is a narrow slit, through which the wire is observed over the centre of

FIG. 15.—The prismatic compass, showing the sighting arrangement and manner of use.

the graduated ring. The prism reflects to the eye the graduation under the slit, so that this, the wire, and the object observed are seen together. The graduation runs from 0° to 360°, the zero lying in the N. point of the magnetic meridian, so that the graduation read is the magnetic azimuth of the object seen through the slit in line with the wire.

In order to get a zero reading under the prism when we are looking magnetic north, the zero of graduation is at the magnetic south end of the needle under the prism.

As the prismatic compass is very generally used, the following section and description of the use of its detailed parts, extracted

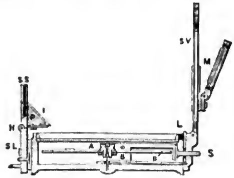


FIG. 16.—Details of the prismatic compass.

A, The needle carrying the graduated ring. The glass prism, P, is cut to 45° upon one face and 90° for the two others, the 90° faces being worked convex, so as to give magnifying power simultaneously with reflection of the ring at right angles, so that the reading of the divisions on the ring appears to stand erect and to be considerably magnified. As the reading is made on the side of the ring nearest the observer, the figures on the ring are engraved right to left. The prism-box has a vertical sight slit, SS, over it which cuts a line with the centre of the top of the prism. The box with its prism moves upwards or downwards in a sliding fitting, SL, by means of a *thumb-nail* stud, which adjusts the prism until it is in exact focus with the divisions on the ring. The back of the prism-box has a hinge, H, so that this box may be closed down to the level of the compass-box to render it portable when out of use.

On the opposite side of the compass-box to that upon which the prism is placed, a long, vertical window, SV, is attached, which has a central hair placed so as to cut a direct line from the slit, SS, in the prism-box across the axis of the needle. This window piece is jointed to turn down upon the face of the compass-box and simultaneously to lift the compass needle off its centre by a part of it pressing the outer end of the lifting lever, L. To prevent too great a continuity of the oscillation of the compass-needle and the ring, through unsteadiness of the hand in holding it, a pin is placed at S, through the compass-box under the window, which carries a light spring, B, that just touches the ring lightly when the pin is pressed in, and thereby brings the compass ring to rest, or fixes it for reading with some degree of certainty.

The mirror, M, is carried in a frame attached to the window, upon which it can slide either up or down. It is jointed with a hinge so as to be set at any angle. By reflection from the mirror, bearings in azimuth are taken much above or below the horizontal plane. Sun-glasses are also provided in front of the prism, which are used for taking the sun's place either with or without the mirror.

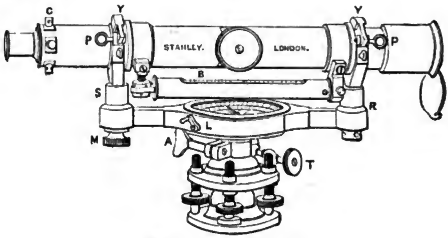


FIG. 17.—Form of Y level.

from Mr. Stanley's book on surveying instruments, may be of service.

When at work, when the box is rotated to bring any object in the

line of the slit and wire produced, the needle, and with it the graduated ring, remains steady.

An ordinary level, furnished with a needle and card, can also be used for taking magnetic azimuths alone. No vertical circle is provided.

CHAPTER V

SIMPLE INSTRUMENTS FOR MEASURING BOTH MAGNETIC AZIMUTH AND ALTITUDE

UNDOUBTEDLY for final observations at any monument a theodolite must be employed, using the sun or a star in order to obtain astronomical or true bearings and so avoid all magnetic difficulties, and reversing the telescope to secure the correct altitude of the horizon. But for rapid surveys there are many handy forms of instrument by means of which preliminary information can be gathered, both with regard to azimuth and, what is equally important, the angular height of the horizon.

It is quite certain that the use of the prismatic compass, in spite of its great convenience, must give way to other instruments which enable us to determine approximately the altitude of the horizon as well as the azimuth of any object the bearing of which we wish to obtain.

As a matter of fact there are now several such instruments available. They consist in the main of an azimuth compass, with an addition generally called a clinometer, enabling angles to be measured in a vertical plane. For this addition the first requisite, of course, is to be able to determine the true horizontal plane at the place of observation. This can be done by using a water level, a pendulum, or a properly adjusted bubble. I will give a brief description of three instruments which are based upon these various methods.

For the angular measurement of elevation, including, therefore, the angular height of the horizon as seen from any monument, the archæologist may use a very simple and convenient addition to the

compass devised by M. Hue, a distinguished French archæologist. He uses the water-level principle. The method employed can be readily gathered from the accompanying woodcuts, obligingly sent to me by the publishers of the "Manual of Prehistoric Researches,"

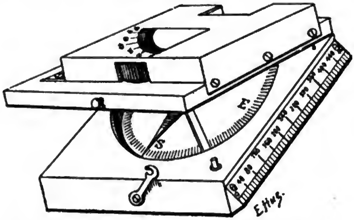


FIG. 18.—M. Hue's combined compass and clinometer.

published by the Société préhistorique de France; a book which shows us, by the way, that the French archæologists are much more thorough and philosophical in their inquiries than their British brethren. It is not a question of the spade *versus* the

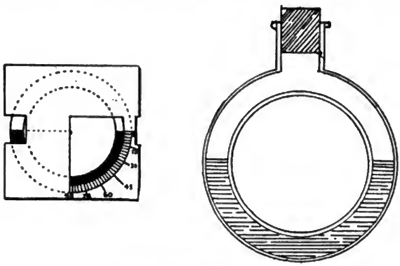


FIG. 19.—Details of the water-level clinometer.

theodolite, but of the spade *and* the theodolite, and as full instructions are given about one as about the other.

It is quite refreshing to read the chapter "Indications pour faire un levé de Terrain à la Boussole," and then the instructions given relating to subsequent work with the large-scale maps published by the French Government.

In Barker's instrument, called for short a clino-compass, we find the pendulum method employed. The altitude zero of the instrument is shown when the pendulum hangs vertically at rest. This is an addition to the azimuth compass, and can be used when the azimuth measures have been made by making the plane of the instrument vertical. The figure will show the method of use. The degrees of elevation can be read under the prism as well as by the pointer at the bottom.

In a reconnaissance lately among the Aberdeen circles I employed a clino-compass of Barker's pattern; it weighs only a few

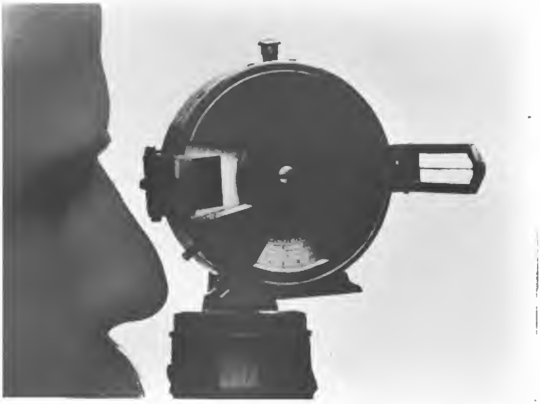


FIG. 20.—Vertical readings with Barker's clino-compass. An elevation of 3° indicated.

ounces and is carried in a sling over the shoulders; even a tripod can be dispensed with, though it is much better to have one; the lightest form is that supplied by the Kodak Company for their cameras, to which must be added an adapter at the top to fit the base and allow the instrument to be used horizontally and vertically. In this form, especially in the case of the altitudes, the mean of several observations should be taken. In my opinion, a desideratum for such work is a simple small instrument with level and reversible telescope for small altitudes only—a miniature

dumpy level, fitting on to the same tripod which carries a full-sized azimuth compass, reading to half-degrees.

The clino-compass sold by Messrs. Casella and Co. is provided with a telescope with cross-wires, fixed to a circular body which contains two dials. One of these carries a magnet and is used for the determination of azimuths; the other is weighted so that it always hangs on its pivot with the same diameter vertical. The exterior edge of each dial is flanged and divided into degrees, the values being read off in the telescope.

The altitude dial is so "dead beat" in its swing that it comes to rest immediately, and the altitude can be read off at once with great accuracy, it being quite easy to estimate the reading to the

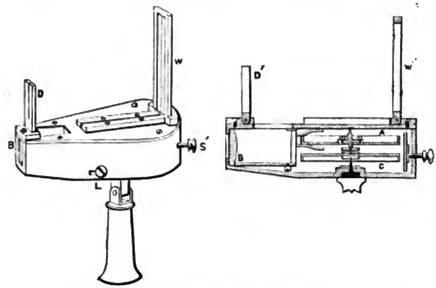


FIG. 21.—Burnier's instrument.

A, compass; B, lens; C, altitude circle; D', W', sights; L, lift; S, stop.

nearest 15′. But the azimuth scale demands an independent stand for accurate work. The magnet being so short, the oscillations are very rapid, and it is a matter of difficulty to obtain a definite reading when the instrument is held in the hand.

Burnier's clino-compass, largely used on the Continent, is somewhat similar to the foregoing, but it lacks the advantage of the telescope and the careful methods of focussing provided.

The details of this instrument will be gathered from the general view and section shown in Fig. 21.

Azimuth and altitude are also provided for in the so-called Verschoyle pocket transit. In this the horizontal plane is provided for by adjusting a bubble in a short spirit level.

The altitude arrangement is on the side of an azimuth compass, the graduations of which are read from the side by a right-angled prism, the graduations being cut on a bevelled edge.

Two advantages are claimed for the Brunton-Pearse pocket mine transit, sold by Messrs. Negretti and Zambra, first its light weight (10 oz.) and portability, and, secondly, it has an adjusting screw which enables the observer to correct the azimuth scale, on the instrument, for the magnetic variation, so that true astronomical azimuths may be read off directly.

Unless the observer has had a fair amount of practice, the absence of a stand makes exact observation difficult, owing to the

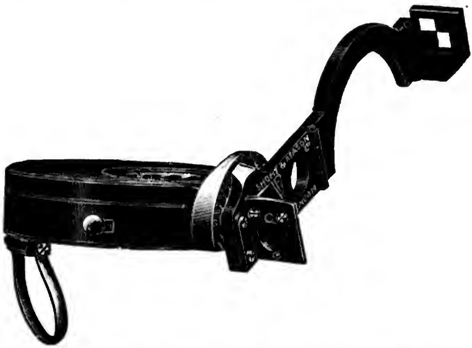


FIG. 22.—Verschoyle's pocket transit, showing the side arm for measurement of altitudes.

vibration of the needle and the necessity of performing several operations simultaneously.

The instrument consists of a magnetic bar needle, an adjustable azimuth scale, and a weighted altitude scale, with a reflector and sight enabling the observer to set on the object.

In taking azimuths the compass is held in the hand with the azimuth-circle horizontal and the sighting bar vertical, the latter being turned away from the observer towards the object to be observed. The reflector is then turned on the hinge until the object to be observed can be seen by the observer looking down at the instrument. This gives, in the mirror, reflections of the object

and the sighting bar, and the instrument is then rotated in the horizontal plane until the reflection of the object, the reflection of the middle of the sighting-bar aperture, and the line drawn on the mirror—parallel to the reflection of the bar—coincide.

In measuring altitudes the lid of the case is placed at an angle of 45° to the compass-box and the instrument is held vertically. The sighting is performed through the hole in the top of the sighting-bar and a hole drilled obliquely through the bottom of the reflector. This arrangement allows the observer to watch the reflection of the bubble whilst keeping his sight on the object

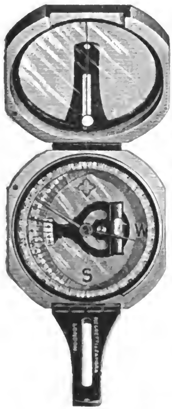


FIG. 23.—The Brunton-Pearse pocket mine transit.

and, by means of a radial arm at the back of the compass-box, to rotate the level until the bubble rests in the middle of its run. Owing to the quick action of the bubble it is rather a delicate operation to keep the sight true, watch the bubble and adjust the level simultaneously, but, with a little practice, close approximations to the true altitude may be obtained.

Observations of magnetic azimuth and altitude can also be made by more complicated instruments, such as theodolites, miners' dials, &c., if, as is generally the case, a magnetic needle is provided for determining the magnetic north point.

The chief point about the theodolite in all its forms is that, whether provided with a needle to give magnetic north or not, observations of sun and stars can be made so that the true or astronomical north can be found.

In the readings of altitude made by any of these instruments, where trees, houses, &c., top the horizon, they should, of course, be

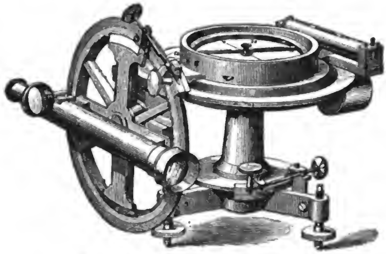


FIG. 24.—One of several forms of the miner's dial, showing the vertical circle for reading altitudes.

neglected, and the elevation of the ground level at that spot taken. Should the top of the azimuth mark (stone, &c.) show above the actual horizon, its elevation should be recorded, as well as that of the horizon.

When using any type of magnetic instrument the observer must be very careful that no iron or steel about his person, *e.g.* a knife or bunch of keys in his pocket, steel spectacles or a steel stretcher in the peak of a motor cap, is interfering with the observation. Again, it is useless to attempt magnetic observations in close proximity to iron railings such as are often employed for fencing, sometimes for enclosing stone monuments.

CHAPTER VI

INSTRUMENTS FOR DETERMINING ASTRONOMICAL AZIMUTH AND ALTITUDE.

BOTH for the determination of astronomical or true azimuths directly, and for accurate observations of altitude, a theodolite is

FIG. 25.—Observing an azimuth with a small theodolite.

essential. It is true, as has been stated, that a theodolite armed with a magnetic needle can provide us with magnetic bearings.

The needle generally supplied with theodolites is of the "trough" pattern, and is fixed to the side of the support; this enables very fine observations to be made.

FIG. 26.—Eyepiece attachment to a theodolite to enable observation of the sun, or a star at a high altitude such as Polaris, to be made.

As we shall see later on, the best use of the theodolite is to deal with true bearings, so that the needle does not come into use.

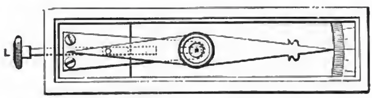


FIG. 27.—Trough compass. L, clamp.

A theodolite is a very complicated instrument, and really little can be learned by a perusal of a description, however long or detailed. The best way of learning how to use it is to get a friend

to give you instructions while you, *yourself*, take each part out of its box, set it up, and then proceed to make some observations with it.

In using a theodolite the various alignments required are referred to some fixed point on the horizon, or at all events some distance away, and the angles determined; the true azimuth of the fixed point is then found by observations of the sun or a star.

(1) If only an approximate azimuth is required, the best means of determining it is by fixing the direction of the sun or a star when it has the greatest altitude. This direction, of course, defines the astronomical meridian, as all heavenly bodies cross it when they are at their greatest altitude.

By using stars of both high and low altitudes a greater exactness can be obtained, but, after all, the method only gives a first approximation, as its weakness lies in the very slow change of altitude as the meridian is approached.

(2) A much more accurate method is that of observing the azimuth of a star when at the same altitude east and west of the meridian. If the mean of the two readings given by the azimuth circle be taken, the resulting reading indicates the direction of the meridian.

(3) To find the meridian line by means of the pole star is a simple and accurate method, as a value can be obtained at *any* time at night by a simple altitude, provided the time of observation is known. Should there not be sufficient time to take the necessary observations, the true bearing of the sun and also of me star can be obtained from Burdwood's azimuth tables.

Full details of all these methods will be given in subsequent chapters.

It is not alone with regard to azimuth that the results obtained by a theodolite far surpass all others in accuracy, as all magnetic difficulties are overcome, and larger circles give us closer and more accurate readings.

In altitude observations the fact that the observing telescope can be reversed and swung round so that all sources of errors of the horizontal plane of the instrument can be eliminated is a matter of equal importance, for in such work, if accuracy is required, as it should be, one setting and one reading are of little use.

CHAPTER VII

WHY THE MEASUREMENT OF ALTITUDE IS NECESSARY

It is now time to enter more into detail on a point to which reference has already been made, as it is one of great importance to all British archæologists, as Britain lies in a mid-latitude. If a star or the sun did not rise or set every day in Britain as happens at the poles, or rose and set vertically, as happens at the equator, the height of the horizon would not come into play.

As a matter of fact, however, in Britain some celestial bodies do rise and set, and *not* vertically; their paths, as we have seen, are inclined to the horizon, and therefore the azimuth of the rising or setting place depends upon the height of the horizon, and I may add that the zenith distance must be less than 90° if the horizon is raised by hills.

In order to consider this matter more closely, I give in the accompanying figures the actual facts of the sunrise on the N.E. horizon at the longest day of the year in two British latitudes, Stenness, lat. 59° N., and Cornwall, lat. 50°. They will illustrate the effect of latitude upon azimuth, a point to be specially considered later, and also the change of azimuth in presence of hills which now specially concerns us. (See Figs. 29 and 30.)

But before we consider them, I must refer to another matter.

The light from sun or star when it enters the earth's atmosphere is refracted or bent out of its course, and the more slantingly it enters the atmosphere, as happens near rising and setting, the greater the refraction. In consequence of this the sun or a star appears higher in the heavens than it really is, and therefore appears to rise earlier and set later.

With regard to the effect of refraction, which we see has to be

taken into account, I give a diagram which shows by a curve the refraction correction necessary for heights of the horizon up to 4°.

There is a relation between the height of the horizon and the refraction correction which may be found useful. If the horizon

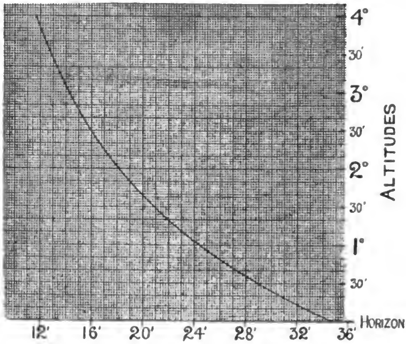


FIG. 28.—Curve showing at bottom the refraction correction (Bessel) in minutes of arc.

is half a degree high, the refraction is practically compensated, as the following table will show :—

Elevation of actual horizon.		Bessel's refraction.		Combined effect.
° ′ ″		′ ″		′ ″
0 0 0	...	34 54	...	−34 54
0 10	...	32 49	...	−22 49
20	...	30 52	...	−10 52
30	...	29 3·5	...	+ 0 56·5
40	...	27 22·7	...	+12 37·3
50	...	25 49·8	...	+24 10·2
1 0	...	24 24·6	...	+35 35·4

In the absence of measurements, it is convenient, therefore, to assume, in the first instance, that the height of the horizon is half a degree; then no refraction correction need be applied.

This relation is utilised in the preparation of general tables and curves, as it provides us with a convenient approximation to the actual azimuth before the height of the horizon has been measured,

In Fig. 29 we see, diagrammatically, the effect of hills and refraction on the azimuth of the summer solstice sunrise in lat. 59°

N. The long dotted line shows the slanting direction of the sun's path in relation to the horizon. The double circle indicates the position of the sun's *centre*, at the sea horizon and neglecting

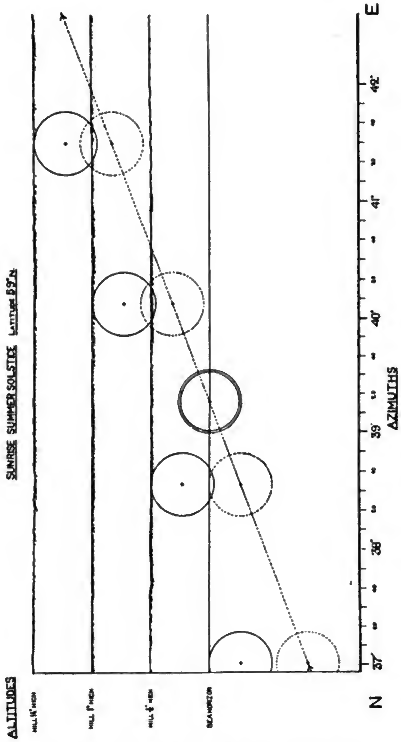


Fig. 29.—The conditions of "sunrise" at the summer solstice in lat. 59° N.

refraction. The azimuth of this position, as shown by the scale at the bottom of the diagram, is N. 39° 16′ E.

The full circles show the *apparent* positions of the sun due to

refraction, at different horizons, if we apply the refraction correction and consider the sun visible with 2′ of its diameter showing, whilst the dotted circles show the *real* position of the sun at the same moment. Thus, considering the lowest full circle in Fig. 29

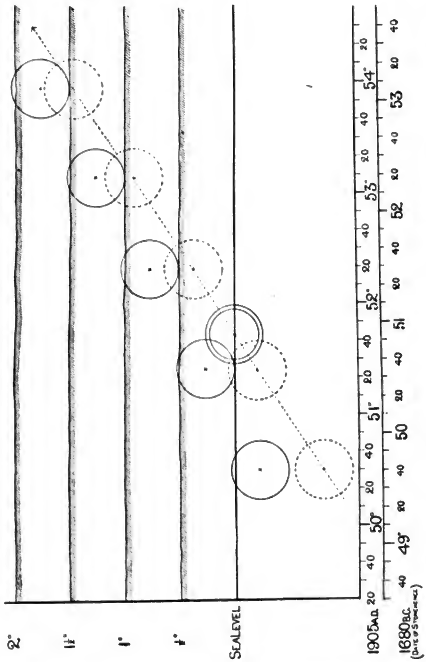


FIG. 30.—Showing azimuths in lat. N. 50° for the summer solstice sunrise, with different heights of hills for 1905 A.D. and 1680 B.C. (From "Stonehenge," p. 290.)

we see that the azimuth of apparent sunrise, with a sea-horizon, is N. 37° 1′ E.

A comparison of the full-line circles with the lower dotted circles in the diagram will give an idea of the degree of apparent change of place brought about in this way; and how the difference

between the true and apparent places rapidly diminishes as the true horizon is left behind. Thus at the sea horizon the true and apparent suns are just separated; with the horizon 1° high they interlock.

The next diagram gives the conditions for lat. 50°. In this latitude, while the sun appears to rise at the present time over the true sea horizon at azimuth N. 50½° E. instead of N. 37° E., as at Stenness, with a hill 2° high the azimuth is very nearly N. 54° E.

Thus we find, in the case of the summer solstice sunrise, it is seen, with sea horizon, in az. N. 37° E. at Stenness and N. 50°30′ E. in Cornwall. A hill 1½° high in lat. 59° changes 37° to 41½°; a hill 2° high in lat. 50° changes 50½ into 54°.

What happens with the solstitial sun also happens with the May and November suns, and warning- and clock-stars. The azimuth changes with the height of the horizon, this, therefore, has to be carefully observed and reckoned with.

Now, while the summer solstice sun thus rises in different azimuths with different heights of the horizon, its position in the heavens, that is, its declination, is unchanged. It is clear, then, that we cannot, by our azimuth measures alone, obtain the true position of the sun in the heavens, that is, in the celestial sphere. The same remark also applies to every star which rises and sets in the latitude of Britain. In addition to the azimuth of the rising or setting place, *we must also take the height of the horizon into account.* When we do this, the determination of the true position in the heavens—the declination, whether of sun or star—is easy.

As I shall show in the sequel, we have now the means, as the result of astronomical calculations, of determining the dates at which the sun or a star occupied declinations in times past different from those they occupy at present. All the archæologist has to do is to consult certain tables in which the sun's declination at the solstice and the varying declinations of the stars are shown for the past six thousand years. This is enough for the purpose, the archæologist has in view.

The change of the azimuth due to the change in declination of the solstitial sun is shown by comparing the two sets of figures at the bottom of fig. 30.

CHAPTER VIII

THE USE OF ORDNANCE MAPS

THE various instruments and methods of work used in such field measurements as the archæological surveyor requires have now been generally referred to. I have next to point out that the Ordnance Maps have been constructed by the use of these instruments and methods among others, so that in the case of many monuments the archæologist will find some of his field work already done for him and plotted in these maps. It is true that most of the work so far done by archæologists on the monuments has dealt chiefly with the minute planning of the various groups of stones, as a guide to, or to aid, the description of objects of various sorts on the ground which lies beneath them. In these matters the Ordnance Maps will not help him, but with regard to the various directions suggested by the arrangement of the stones, a matter which has hitherto been either completely neglected or insufficiently indicated, the maps may be utilised.

Indeed for the directions or *azimuths* of the sight-lines the investigator cannot do better than use the maps themselves. Their accuracy is of a very high order and is not likely to be exceeded, even if approached, by any casual observer with simple instruments or having to make his own special arrangements for correct time before he can begin his surveying work.

I was informed by Colonel Johnston, R.E., the late director of the Ordnance Survey, that the possible error of position of a stone on the 25-inch map does not amount to more than 6 feet.

When it is recognised that the surface can give us as valuable information as underground digging, and when a theodolite or some equivalent instrument, however simple, takes its place along with the pick and spade in the equipment of the archæologist, the

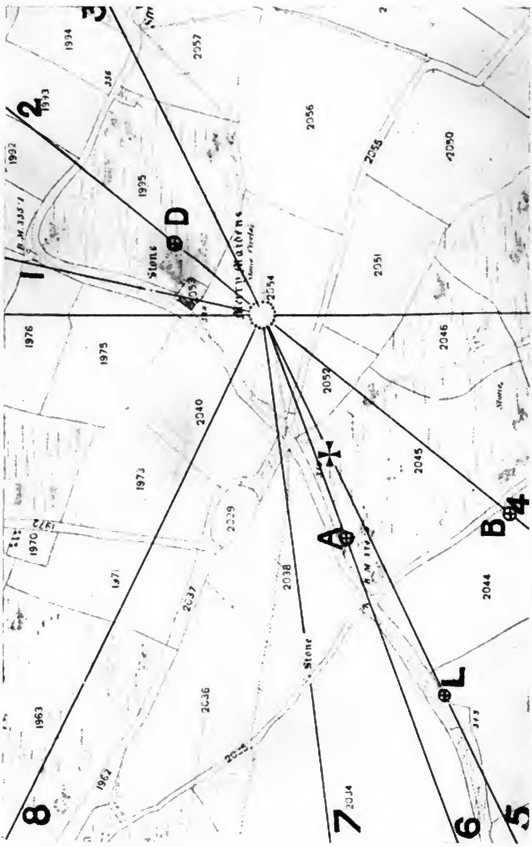


FIG. 31.—25-inch Ordnance Map of Merry Maidens, showing alignments obtained by a circular protractor.

tremendous service which the Ordnance Maps can render will be fully recognised. The maps can even sometimes render field surveys unnecessary. But if these are to be undertaken, a study of the maps is the first necessary step, whichever monument we wish to deal with. This study will show us that the ordnance surveyors have provided us with an immense amount of accurate archæological information, and the 25-inch map in the case of some of the larger monuments provides us with a sufficiently large working scale. 25 inches to a mile means 74 yards to 1 inch.

In the case of an avenue, a large circle with outstanding stones, or a cromlech with a creepway, it is really a loss of time to visit the monument before the map has been well studied.

Indeed it is not too much to say that the 25-inch maps of the Ordnance Survey have put into the hands of archæologists a tremendous engine of research, from which true azimuths can be at once found without the intervention of a magnetic instrument in the field.

To measure any required direction, or azimuth, on these maps a small instrument called a *circular protractor* is all that is necessary to provide us with the required angular values of the directions or azimuths.

The protractor is provided with a well-marked centre and a movable pointer with a vernier reading to minutes of arc over a graduated circle marked into 360°.

If the azimuth is required from any point on the map to any other, a pencil line is drawn joining the points. Through the point from which the angle is to be measured another line is drawn parallel to one of the side lines on the map. This represents a north and south line, the north point lying over the top of the map. The central cross-wire of the instrument is then brought to the intersection, and the circle so placed that the zero of graduation lies on the N. and S. line; the pointer is then moved till its direction is coincident with the line through the object, and the angle is read. This is the required azimuth. A circular protractor employed in this manner is shown in the accompanying figure.

In the case of the avenue represented, a line some 12 inches long is drawn parallel to its length. Another line is then drawn parallel to the side of the map, which is always a N. and S. line, or very nearly so. The zero of the protractor is brought on the N.

and S. line, and the centre on the point of intersection. The angle between the two lines is the azimuth.

When using the 25-inch maps for determining azimuths it must be borne in mind that the side-lines are not always exactly due north and south. If very accurate results are required, the Director-General of the Ordnance Survey, Southampton, will

FIG. 32.—The circular protractor measuring the azimuth of an Avenue on a 25-inch Ordnance Map of Dartmoor.

probably on application state the correction to be applied to the azimuths on this account; and this should be applied, of course, to each of the values obtained.

In some cases, it may be found that the Survey has not included every outstanding stone which may be found on making a careful search; many of the stones are hidden by gorse, etc., and are not, therefore, easily found.

When this happens, the azimuth of some object that is marked on the map should be taken as a reference line, and the difference of azimuth between that and the unmarked objects determined by the circular protractor. In this way the azimuths of all the sight-lines may be obtained.

The Ordnance Survey maps may also be employed *in a preliminary reconnaissance* to obtain approximate values of the horizon elevations. This may be done by measuring the distances and contour-lines shown on the 1-inch maps along the alignment. This method, however, is only very roughly approximate, owing to the fact that sharp but very local elevations close to the monuments may not appear on these maps and yet be of sufficient magnitude to cause large errors in the results.

The following heights above the level of the monument correspond to the previous assumption of hills $\frac{1}{2}°$ high:

Distance 1 mile.	Height = 46 feet.
,, 2 miles.	,, = 92 ,,
,, 4 ,,	,, = 184 ,,
,, 8 ,,	,, = 368 ,,
,, 10 ,,	,, = 460 ,,

In the future the Ordnance Maps will render still another service to archæologists. In new editions of the 1-inch map the magnetic variation of the region covered will be shown at the side.

CHAPTER IX

WHY THE SUN'S AZIMUTH CHANGES THROUGHOUT THE YEAR

So far I have written of the declination and azimuth of the Sun or a star.

I have now to point out that the conditions of the Sun are vastly different from those of a star.

For our present purpose we may consider the position of the stars on the celestial sphere—that is, their declinations,—as changeless; there is a very slow change which will occupy us by and by. But the Sun is for ever changing its declination, and therefore its azimuth. Why is this?

The relation of the Earth to the Sun is quite different from its relation to the stars. The Earth, spinning on its axis once a day, moves round the Sun, which is comparatively close to it, once a year, while both Sun and Earth may be considered as being at the centre of the universe of stars infinitely removed.

So we have two movements to consider: the Earth's daily spin or rotation, and its yearly travel, its revolution, round the Sun; and the yearly movement is as truly reflected in the apparent yearly movements of the Sun and stars as is the daily movement, as we have seen.

Thirty years ago, in endeavouring to make the effects of the yearly motion clear by a concrete example, I used as an illustration a tub of water, and I can think of nothing better now. The plane of the Earth's motion round the Sun, called *the plane of the ecliptic,* is represented by the surface of water in the tub. We have the Sun, a large ball in the centre, and the Earth, a smaller ball, represented in four positions in its orbit round it. The balls are half immersed. Now set the balls spinning with the Earth's axis upright as shown. The plane of the Earth's equator

and the water surface coincide, and therefore from whatever point of the Earth's orbit we view it, the Sun will always be seen in the plane of the Earth's equator : in other words its declination will be always 0°, as declination means distance from the equator, and I

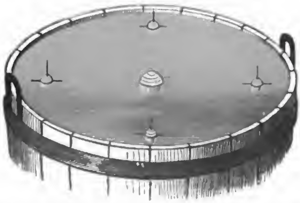


FIG. 33.—The plane of the ecliptic with the Earth in four positions in its orbit. The Earth's axis is upright in regard to the water surface representing the plane of the ecliptic.

may add that the length of the day would always be the same.

But the Earth's axis is *not* upright—that is, perpendicular—to the plane of the ecliptic.

The real state of things is represented in Fig. 34. The plane of the Earth's daily movement, the plane of the equator, does not

FIG. 34.—Earth with axis inclined to the water surface representing the plane of the ecliptic.

coincide with the plane of the ecliptic represented by the water surface. In consequence of this, at two opposite points in the orbit the Earth's axis will be most inclined towards the sun ; in one case the north pole will be on the hemisphere turned towards it ; on the other it will be on the hemisphere turned away from the Sun.

The point which chiefly concerns us is that, under these circumstances, the declination of the Sun is continually changing. It will have its greatest northern declination when the N. pole is most turned towards it, and the greatest southern declination at the opposite point of the Earth's yearly path round it. At the two intermediate points represented by the upper and lower balls the Sun will appear to cross the equator and so have declination 0°.

For details of the full effects thus brought about I must refer the reader to pp. 41-54 of my Primer of Astronomy. It must suffice here to refer to a new crop of technical terms which the British archæologists must be familar with. In the first place we may define the *year* as the time taken by the Earth in its annual journey from any of the four positions referred to till it returns to it. In Welsh tradition the year begins when the N. pole is turned away from the Sun, when the Sun has reached its greatest southern declination and is so seen low down in the south in the depth of winter. For about three days the declination scarcely changes. The Sun rises and sets in the same position on the horizon for each of these days; the Sun stands still, we have the *Solstice*—the Winter Solstice. Then begins its northern journey. The Sun-God is born, and goes on increasing in strength and light till six months afterwards it arrives at its highest northern point of declination when the N. pole is most fully bathed in the Sun's rays. Here we have another solstice, another three days of equal azimuth at rising and setting, this time the Summer Solstice.

In the latitude of Cornwall (50° N.) the Sun's azimuth at the Winter Solstice with a sea horizon is S. 53° E. from the S. point or N. 127° E. from the N. point in the two ways of reckoning it that have already been stated. At the Summer Solstice with a sea horizon it is N. 50° E., so that there is a change of azimuth in the Sun's place on the horizon amounting to 77° between the two solstices.

At two intermediate points when the Sun appears to cross the equator we have the *equinoxes*, times of the year when the Sun at 0° declination rises all over the world in Az. N. 90° E., and its daily change in declination and therefore in azimuth is most rapid. At this time the nights are of equal length everywhere, hence the term.

What then is the origin of the change of declination which determines the change of azimuth? This depends upon the angle between the plane of the Earth's spin and that of its movement round the Sun—that is, between the plane of the equator and the plane of the ecliptic. This angle, termed the *obliquity of the ecliptic*, determines the sun's declination at the solstices. At the present time it is 23° 27′; the angle was greater in past times, and therefore the sun's declination at the solstices was greater than it is now, so that its azimuth at the solstice was less. See Fig. 30.

CHAPTER X

THE EFFECT OF LATITUDE ON AZIMUTH

It should be now clear that the chief astronomical problem in front of the archæologist when he is measuring the direction of an ancient sight-line, whether on the 25-inch map or in the field, is to determine the true place in the heavens in relation to the celestial equator—that is, the *declination*—of any body, whether sun or star, the rising or setting of which may have been observed along that sight-line. In old times the circle of the horizon was the only intrument at man's disposal; risings and settings on this horizon were therefore the chief things noted.

It has already been shown that, at the same place and the same height of horizon, all celestial bodies with the same declination rise and set in the same azimuth. A few minutes with a celestial globe, setting the pole of the heavens at different elevations above the wooden horizon so as to represent the conditions in different latitudes (for, as we have seen, the elevation of the celestial pole is the same as the latitude of a place), will soon show that the azimuth, the rising or setting place of a star of any declination (except 0°), changes with the latitude of the place of observation.

It follows from this that, to take one instance, the azimuth of the sunrise at the summer solstice will continuously change as it is observed from the south of England to the north of Scotland; and the change in the azimuth really proves that we are dealing with the *same* direction, or, in other words, with a celestial body in the same declination.

In order to show how the effect of different latitudes works out, from the present point of view, I give here a diagram which deals with British latitudes and shows how celestial bodies with declinations (shown to the left) from 0° to 46° N. or S. rise or set in

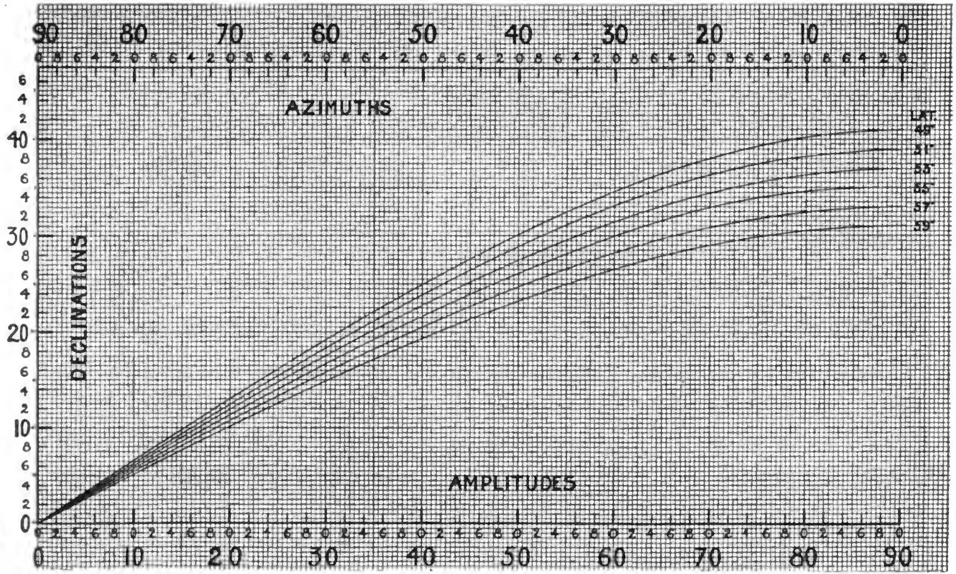


Fig. 35.—Curves for finding declination from given azimuths or amplitudes of a body on the horizon in British latitudes.

different azimuths (shown at the top) according as the place of observation is situated in different latitudes.

Let us suppose that an azimuth has been measured in a certain latitude. Several curves connecting the values are drawn for different latitudes from 49° to 59° N., and care must be taken by the observer to use that one corresponding to the latitude in which he is working. Knowing the azimuth (or amplitude), find where the vertical line corresponding to that azimuth (or amplitude) cuts the special curve for the latitude, and from the point of intersection run along the horizontal line to the scale of declinations given at the left-hand side of the diagram. Thus, azimuth 10° in lat. 49° gives us declination 40°, while in lat. 59° it gives declination 30°.

But the use of the diagram is not confined to showing this effect of change of latitude. It may be conveniently used to obtain approximate declinations to be determined from the field observations of any monuments between Land's End and John o' Groats, whether the direction is recorded by amplitude or azimuth; the declination is read at the side from the value of either, indicated, say, by a dot, on the proper latitude curve.

CHAPTER XI

SIMPLE MEANS OF FIXING A MERIDIAN LINE

In the previous chapters I have endeavoured to show how the azimuths of the sight-lines which the archæologist has to investigate are affected by the height of the horizon at, and the latitude of, the place of observation.

But the archæological surveyor wants more than this; he must be able to determine his meridian and, depending upon this, his azimuth, for himself, when engaged in the survey of any monuments in any region. The various methods of doing this must now occupy attention.

The determination of the meridian which marks the true N. and S. points at any place of observation is really the basis of all methods of determining azimuths or true bearings. For the surveying work of archæologists this determination of azimuths or true bearings is of fundamental importance.

However the measurements are made, the method usually employed is to obtain a reading on the horizontal circle of a reference point, which should be about a mile away, and then to measure the angular distances from it of the points required for the survey. The *true bearing* of this reference point is then determined by one of the various methods described below.

I will begin by referring to the methods available for the determination of a meridian line, beginning with the simplest.

(1) *By a Gnomon.*

On a piece of level ground erect a wooden rod, about 4 feet in length, and by means of a plumb-line make it vertical. An hour or two before noon, mark the extremity of the shadow and measure its distance from the base of the rod. In the

afternoon, when the shadow is again the same length, make a second mark; then the line bisecting the angle formed by the two marks and the base of the rod lies in the meridian.

To prevent the morning observation being rendered useless by the clouding out of the afternoon observation, three or four marks should be made, at intervals, in the morning.

(2) *By an observation of the sun when "apparent time" is accurately known.*

Apparent time is the time counted by the meridian passage of the actual sun at the place of observation, and in order to obtain it the observer must know the correct Greenwich Mean Time, the equation of time and the longitude, E. or W. of Greenwich, of the place of observation.

Greenwich Mean Time is that shown by the post-office and railway clocks, in Great Britain, and exact 10 a.m. is received, by telegraphy direct from Greenwich, at every post office each morning.

Having his watch set to Greenwich Mean Time, or its error carefully noted, the observer obtains local apparent time by (1) adding, or subtracting, the "equation of time," that is, the difference between the times of the meridian passage of the true, apparent, sun and of the meridian passage of the fictitious, mean sun, given in Fig. 36; and (2) by adding, or subtracting, the difference, four minutes for each degree, due to difference of longitude E. or W. of Greenwich.

To find the direction of the meridian, all that is necessary is to mark the direction of the sun at local apparent noon.

The observation may be made with a theodolite, surveyor's transit, or other instrument provided with the means of measuring horizontal angles.

Supposing that a theodolite is being used, it should usually, owing to the great altitude of the sun at noon, be fitted with a diagonal eye-piece allowing the observer to assume a comfortable position (Fig. 26) whilst making the observations. A dark-glass should, of course, always be fitted over the eye-piece to protect the eye from the sun's dangerous glare.

Some time before apparent local noon, determined by the corrections to the observer's watch time, the theodolite should be adjusted (*i.e.* levelled, &c.) and the azimuth circle and verniers

brought to the reading 180° 0′ 0″; this circle is then clamped, and the subsequent movement in azimuth made by turning the whole instrument about the lower pivot. The telescope is then directed to the sun, which is to be kept bisected by the cross-wires by means of the fine-adjustment screws until the exact moment of apparent noon. The telescope then points along the meridian, towards the south, with the reading on the azimuth circle 180° 0′ 0″. All

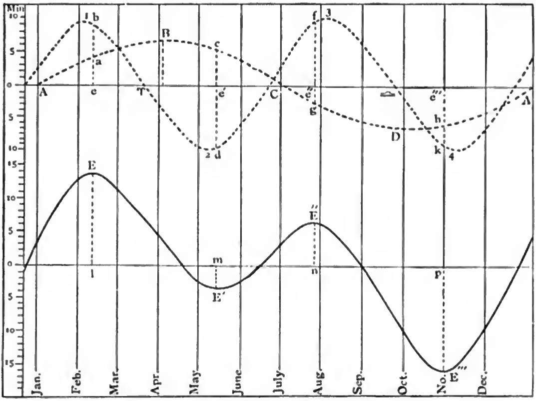


Fig. 36.—Diagram illustrating the equation of time.

The equation of time is derived from two components.

The curve A B C D represents the differences between the mean and true suns at different times of the year, due to the varying velocity of the earth's motion round the sun.

The curve 1 2 3 4 represents the differences due to the obliquity of the ecliptic.

The equation of time curve E E′ E″ E‴ is derived by taking the algebraical sum of the ordinates of the other two.

Ordinates above the datum lines are positive (+), those below are negative (−). Sometimes the ordinates of the two components act against each other, but at other times they act together. Thus, on April 15 the + due to curve A B C D is exactly neutralised by the − due to 1 2 3 4, and the equation of time is *nil*, but on February 11 they act together, and the resulting equation of time is + 14½ minutes.

azimuths may now be referred to this line, care being taken to keep the lower circle clamped and to make all the rotations in azimuth with the vernier circle only.

The method usually followed is first to ascertain the true bearing of a reference point—which should be at a distance of about a

mile—and then to measure from this the azimuths of other required points.

(3) *By observations of the sun about the time of apparent noon, exact time not being available.*

If the time is *not* accurately known, the preceding method cannot be employed, but the following simple, but only approximate, method may be utilised.

Some minutes before apparent noon adjust the theodolite, clamping the vernier circle, so that the reading is 180° 0′ 0″. Then unclamp the lower circle, and by rotating it and the altitude circle direct the telescope to the sun; the diagonal eye-piece and the dark-glass should, of course, be employed. Make the horizontal cross-wire tangential to the sun's upper limb, *i.e.* the lower limb seen in the inverting telescope. It will be noticed that the altitude of the sun continues to increase, and that in consequence the limb falls below the horizontal cross-wire. Using the fine adjustments in azimuth (on the lower circle) and altitude, keep the cross-wire tangential to the upper limb until no further change in altitude takes place (after this the altitude will begin to decrease). The sun is then at the highest point of its diurnal path as seen from the place of observation, that is to say, the sun is due south of the observer, or in other words, it is the moment of local apparent noon. Clamp the theodolite in this position, and make the subsequent motions in azimuth with the upper, vernier, circle as directed at the end of the second method.

This method is, at the best, only an approximate one, because the change of the sun's altitude near noon is very slow, and it is a difficult matter to determine exactly the moment at which the sun is at its highest point.

(4) *By observations of stars at equal altitudes E. and W.*

Select any star about 45° above the horizon, and about an hour E. of the meridian. Having very carefully adjusted the instrument, clamped the vernier plate at 0° and unclamped the limb, bisect the star by the cross-wires, clamp the telescope in altitude, and read and take the mean of the altitude verniers; also clamp the horizontal limb and unclamp the vernier plate. When the star has passed the meridian, and descends to near the altitude at which it was first observed, move the telescope round in azimuth, without disturbing any of its adjustments, as nearly

as possible to the position of the star, and watch for its reappearance in the field of view. Move the telescope in azimuth so that the star shall be again bisected by the cross-wires at the same altitude as before.

Read off the horizontal limb. The telescope will be in the meridian when it is placed half-way between the two readings.

Then mark the direction of the meridian by a line of pickets driven in by an assistant or note the true bearing of a distant object if one is visible.

In the case of the sun observations referred to above, sometimes, especially in rocky localities where it is difficult to drive in pickets, it is better to clamp the lower plate on to a distant object as a reference mark before observing the sun, the upper plate being set to zero. Then unclamp the upper plate and follow the sun until it is noon by the corrected watch. The angle thus obtained is the true bearing of the distant object from the south to which all other bearings should be referred. Some observers prefer always to use this method.

CHAPTER XII

TO FIX A MERIDIAN LINE BY THE POLE STAR

THE mean declination of the Pole Star, otherwise called Polaris (*a* Ursæ Minoris), is N. 88° 48′; its position, then, is slightly over 1° from the true pole.

As an approximate method of determining the N. and S. line, observation of the Pole Star is one of the simplest and most accurate. The observations may be made when the Pole Star on its journey, in a very small circle, round the true pole, is due N. when it crosses the meridian above or below the true pole, or when it is at its greatest distance either east or west from the pole.

With a well-adjusted instrument and accurate local time, the former is a little the simpler method, but the latter is generally the more accurate because at the elongations the apparent motion of the Pole Star in azimuth is least; consequently a small error in time has practically no effect on the accuracy of the observation.

Whether a transit or an elongation is to be observed will depend upon which occurs at the most convenient time.

The following table shows the times of occurrence for the year 1909 at convenient times in the evening or morning for every tenth day; for the intervening dates the time determined by interpolation may be taken.

To make the observation, whether of transit or elongation, set up the instrument with its vertical axis directly above a peg driven into the ground, adjust it carefully and bring the reading on the azimuth circle to zero. Clamp the vernier circle and make

TIMES OF TRANSITS AND ELONGATIONS OF POLARIS, 1909.

(*Annuaire du Bureau des Longitudes.*)

Date, 1909.	G. M. T. of Transit. + signifies upper passage. − „ lower „		G.M.T. of Eastern Elongation.	G.M.T. of Western Elongation.
	h. m.		h. m.	h. m.
January 1	6 43·5 p.m.	+		
2				12 37·5 a.m.
11	6 4·0 p.m.	+		11 58·0 p.m.
21	5 24·5 p.m.	+		11 18·5 p.m.
21	5 26·5 a.m.	−		
30				10 43·0 p.m.
31	4 47·0 a.m.	−		
February 9				10 3·5 p.m.
10	4 7·5 a.m.	−		
19				9 24·0 p.m.
20	3 28·0 a.m.	−		
March 1				8 44·6 p.m.
2	2 48·6 a.m.	−		
11				8 5·1 p.m.
12	2 9·1 a.m.	−		
21				7 25·7 p.m
22	1 29·7 a.m.	−		
31				6 46·4 p.m.
April 1	12 50·4 a.m.	−	6 54·4 a.m.	
10				6 7·0 p.m.
11	12 11·0 a.m.	−	6 15·0 a.m.	
12				5 59·2 p m.
13	12 3·2 a.m.	−	6 7·2 a.m.	5 55·3 p.m.
14			6 3·3 a.m.	
21	11 27·8 p.m.			
22			5 31·8 a.m.	
May 1	10 48·5 p.m.	−		
2			4 52·5 a.m.	
11	10 9·1 p.m.	−		
12			4 13·1 a.m.	
21	9 30·1 p.m.	−		
22			3 34·7 a.m.	
31	8 50·9 p m.	−		
June 1			2 54·9 a.m.	
10	8 11·7 p.m.	−		
11			2 15·7 a.m.	
20	7 32·6 p.m.	−		
21			1 36·6 a.m.	
30	6 53·5 p.m.	−		
30	6 55·4 a.m.	+	1 1·4 a.m.	
July 1			12 57·5 a.m.	
10	6 16·3 a.m.	+	12 22·3 a.m.	
19			11 43·1 p.m.	
20	5 37·1 a.m.	+		
30	4 58·0 a.m.	+		
August 8			10 24·8 p.m.	
9	4 18·8 a.m.	+		
18			9 45·6 p.m.	
19	3 39·6 a.m.	+		

TIMES OF TRANSITS AND ELONGATIONS OF POLARIS, 1909—*continued.*

Date, 1909.	G.M.T. of Transit. + signifies upper passage. − „ lower „		G.M.T. of Eastern Elongation.	G.M.T. of Western Elongation.
	h. m.		h. m.	h. m.
August 28			9 6·5 p.m.	
29	3 0·5 a.m.	+		
September 7			8 27·3 p.m.	
8	2 21·3 a.m.	+		
17			7 48·0 p.m.	
18	1 42·0 a.m.	+		
27			7 8·8 p.m.	
28	1 2·8 a.m.	+		
October 7			6 29·5 p.m.	
8	12 23·5 a.m.	+		6 17·5 a.m.
12			6 9·9 p.m.	
13	12 3·9 a.m.	+		5 57·9 a.m.
13	11 59·9 p.m.	+	6 5·9 p.m.	
14				5 53·9 a.m.
18	11 40·3 p.m.	+	5 46·3 p.m.	
19				5 34·3 a.m.
28	11 1·0 p.m.	+	5 7·0 p.m.	
29				4 55·0 a.m.
November 7	10 21·6 p.m.	+	4 27·6 p.m.	
8				4 15·6 a.m.
17	9 42·3 p.m.	+		
18				3 36·3 a.m.
27	9 2·8 p.m.	+		
28				2 56·8 a.m.
December 7	8 23·4 p.m.	+		
8				2 17·4 a.m.
17	7 44·0 p.m.	+		
18				1 38·0 a.m.
27	7 4·5 p.m.	+		
28				12 58·5 a.m.
31	6 48·7 p.m.	+		
January 1 (1910)				12 42·7 a.m.

all subsequent adjustments of azimuth by means of the lower circle.

Turn the telescope to Polaris, and with the fine-adjustment screw of the lower circle keep the star on the middle vertical cross-wire till the moment of transit or elongation. If the place of observation be west of Greenwich, four minutes must be added to the tabular time for each degree of longitude.

At the time of a transit the telescope points N. true and the vernier should read 0°. The azimuth of a very definite object, illuminated if necessary, must then be noted, so that in daylight when the theodolite is again placed over the peg the meridian

can be found. If an elongation has been observed, a correction must be applied for the azimuth of Polaris, care being taken to make the correction E. or W. according to whether a W. or an E. elongation has been observed. This departure from the meridian varies with the latitude as under:

Lat. N.	Azimuth at elongation. (E. or W.)	Lat. N.	Azimuth at elongation. (E. or W.)
° 50	° ′ 1 50	° 55	° ′ 2 3
51	1 52	56	2 7
52	1 55	57	2 10
53	1 57	58	2 14
54	2 0	59	2 17

In the *Connaissance des Temps*, published by the Paris Bureau des Longitudes, there is a table (pp. 684—689, 1908 edition) which gives the azimuths of Polaris for every ten minutes of time in each degree of latitude.

If this table be available there is no necessity to wait for an elongation or transit, which may take place at an awkward hour, because the azimuth given on the tables may be employed straightaway to determine the meridian.

To find the azimuth from the tables the observer must know the latitude of the place of observation and the hour angle of Polaris. The former may be found, by inspection, from an Ordnance map, and the latter is easily calculated if the sidereal time, and the R.A. of the star, be known. This angle, usually designated H.A. or h, is the angular distance of the star from the meridian measured at the pole and reckoned in time; thus, when the star is on the meridian, south of the pole, the hour angle is 0h. 0m., when it is at western elongation the hour angle is 6h. 0m. W., and so on.

But it is unnecessary to know the meridian before obtaining the hour angle, for we know, by definition, that the first point of Aries crosses the meridian at 0h. 0m. 0s., sidereal time, whilst the right ascension of a star is the angular distance of the star, usually measured in time, along a parallel of declination, from the first point of Aries.

Thus the angular distance between the right ascension of the

star and the sidereal time is the hour angle of the star. For example, the R.A. (right ascension) of Polaris is 1h. 26·5m.; therefore, if the sidereal time be 6h. 0m., that is to say, the first point of Aries is 6h. 0m. past the meridian, the hour-angle of Polaris is 6h. 0m. − 1h. 26·5m. = 4h. 33·5m.; in other words, Polaris is 4h. 33·5m. past the meridian.

The sidereal time at mean noon for each day may be found by consulting the Nautical Almanac, or Whitaker's Almanac and similar works, and to find it at any subsequent hour it is only necessary to add the equivalent as shown in the following table:—

To Reduce Mean to Sidereal Time.

Solar hours.	Add min. sec.	Solar min.	Add sec.	Solar min.	Add sec.	Solar sec.	Add sec.	Solar sec.	Add sec.
1	0 9·86	1	0·16	31	5·09	1	0·00	31	0·08
2	0 19·71	2	0·33	32	5·26	2	0·01	32	0·09
3	0 29·57	3	0·49	33	5·42	3	0·01	33	0·09
4	0 39·43	4	0·66	34	5·59	4	0·01	34	0·09
5	0 49·28	5	0·82	35	5·75	5	0·01	35	0·10
6	0 59·14	6	0·99	36	5·91	6	0·02	36	0·10
7	1 9·00	7	1·15	37	6·08	7	0·02	37	0·10
8	1 18·85	8	1·31	38	6·24	8	0·02	38	0·10
9	1 28·71	9	1·48	39	6·41	9	0·03	39	0·11
10	1 38·56	10	1·64	40	6·57	10	0·03	40	0·11
11	1 48·42	11	1·81	41	6·74	11	0·03	41	0·11
12	1 58·28	12	1·97	42	6·90	12	0·03	42	0·12
13	2 8·13	13	2·14	43	7·06	13	0·04	43	0·12
14	2 17·99	14	2·30	44	7·23	14	0·04	44	0·12
15	2 27·85	15	2·46	45	7·39	15	0·04	45	0·12
16	2 37·70	16	2·63	46	7·56	16	0·04	46	0·13
17	2 47·56	17	2·79	47	7·72	17	0·05	47	0·13
18	2 57·42	18	2·96	48	7·89	18	0·05	48	0·13
19	3 7·27	19	3·12	49	8·05	19	0·05	49	0·13
20	3 17·13	20	3·29	50	8·21	20	0·05	50	0·14
21	3 26·99	21	3·45	51	8·38	21	0·06	51	0·14
22	3 36·84	22	3·61	52	8·54	22	0·06	52	0·14
23	3 46·70	23	3·78	53	8·71	23	0·06	53	0·15
24	3 56·56	24	3·94	54	8·87	24	0·07	54	0·15
25	4 6·40	25	4·11	55	9·04	25	0·07	55	0·15
26	4 16·26	26	4·27	56	9·20	26	0·07	56	0·15
27	4 26·13	27	4·44	57	9·36	27	0·07	57	0·16
28	4 36·00	28	4·60	58	9·53	28	0·08	58	0·16
29	4 45·86	29	4·76	59	9·69	29	0·08	59	0·16
30	4 55·71	30	4·93	60	9·86	30	0·08	60	0·16

Example.—Find the azimuth of Polaris in lat. 50° N., at 10 p.m. G.M.T., May 6, 1908, using the table given in the *Connaissance des Temps* (p. 689, 1908).

	h. m. s.
Sidereal time at mean noon, May 6, 1908, from Whitaker's Almanac (1908), p. 35	2 55 45
Sidereal time equivalent of 10h. solar time, from table given above, neglecting fractions of a second	10 1 39
Sidereal time at 10 p.m. G.M.T. May 6, 1908	12 57 24
R.A. of Polaris	1 26 30
Therefore hour angle of Polaris at 10 p.m. G.M.T.	11 30 54
From *Connaissance des Temps*, azimuth of Polaris at hour angle 11h. 30m. in lat. 50° N. is	14′ W.
And at 11h. 40m. in lat. 50° N. is	9′ W.
Therefore at 11h. 31m., by interpolation, the azimuth is	13·5′ W.

Having found this azimuth, the direction of the meridian is determined by the method shown in the previous chapter.

CHAPTER XIII

TO DETERMINE AZIMUTHS BY BURDWOOD'S TABLES

THE data given in Burdwood's tables enable the observer to find the azimuth of the sun at any hour of the day between 6 a.m. and 6 p.m., and in any latitude between 60° N. and 60° S.; the method of using them is as follows.

In order to find the azimuth the observer must know (1) the *apparent* time (2) the latitude of the place of observation, and (3) the declination of the sun's centre at the moment of observation. Knowing these, the determination of the azimuth is simply a matter of interpolation, as shown in the following example :—

To find the azimuth of the sun at 4 *p.m.* "*mean time*" *on May* 6, *in lat.* 51° 30′ *N. and long.* 3° *W.*

In the first place it is necessary to find the equivalent in *apparent time* of 4 p.m. mean time on May 6, and this involves corrections for the equation of time and difference of longitude.

The value of the former correction may be obtained from the curve (Fig. 36) given on p. 55, and is stated, in detail, in the Nautical Almanac, for each day. For May 6 (1908) the Almanac gives "3m. 29s. to be *added* to mean time" as the correction; thus 4 p.m. mean time is 4h. 3m. 29s. apparent time.

The longitude correction amounts to 4 minutes of time for every degree of longitude, added if the place of observation be E. of Greenwich, subtracted if it be W. Thus, as the supposed place of observation is 3° W. of Greenwich, $4 \times 3 = 12$ minutes must be subtracted, and the local apparent time becomes 4h. 3m. 29s. − 12m. 0s. = 3h. 51m. 29s.; this may be taken as 3h. 51·5m.

The second datum required is the latitude of the place of observa-

tion, and, if it is not already known, this may be found to the nearest 6′—1′ by estimation—on the one-inch Ordnance Sheet of the locality.

The declination of the sun's centre is given for noon each day in the Nautical Almanac, and for intermediate times may be found by interpolation. For noon May 6 (1908) the almanac gives 16° 30′ N. as the declination, and for noon May 7, 16° 47′ N.; interpolating we get 16° 38′ N. as the declination at 4 p.m. on May 6.

Thus the data we have to use in the tables are:—local apparent time, 3h. 51·5m.; latitude, 51° 30′ N., and declination 16° 38′ N.

Turning to the page in the tables which gives the azimuths for lat. 51° "declination same name as latitude" (p. 215, 1888 edition) we get:—

	Apparent time 3h. 48m. p.m. and declination 16°, azimuth =	106° 8′
	,, ,, 3h. 52m. p.m. ,, ,, ,, ,, =	105 15
(1) therefore	,, ,, 3h. 51·5m. p.m. ,, ,, ,, =	105 21

Again,

	Apparent time 3h. 48m. p.m. and declination 17°, azimuth =	105° 23′
	,, ,, 3h. 52m. p.m. ,, ,, ,, ,, =	104 30
(2) therefore	,, ,, 3h. 51·5m. p.m. ,, ,, ,, =	104 37

Interpolating, we get,

(3) Apparent time 3h. 51·5m. p.m. and declination 16° 38′, azimuth = 104° 53′

(4) By a similar process we find, from the table for lat. 52° N., that the azimuth at 3h. 51·5m. p.m. with declination 16° 38′ N. is... 105° 31′

Interpolating from (3) and (4) we get the value for the azimuth, in latitude 51° 30′, as 105° 12′. This is the value we are seeking, and is the azimuth of the sun at 4 p.m. Greenwich Mean Time (G.M.T.) on May 6 (1908) in lat. 51° 30′ N. long. 3° W.

All this can, of course, be worked out at any time before the observation is made, so that the observer may set up his instrument, properly adjusted and fitted with diagonal eye-piece and dark-glass, before the moment for which the azimuth has been derived.

The value obtained is, as stated in the footnotes to the tables, the azimuth reckoned from N. through W., and as the theodolite circles usually read from 0° to 360° through E., we must subtract this value from 360° in order to get the azimuth as usually taken, *i.e.* from N. through E., S., and W. to N. again. Thus our azimuth becomes $360° - 105° 12' = 254° 48'$, and this value should be set on the upper vernier circle, which should then be clamped. With the

lower, limb, circle unclamped, the telescope is directed to the sun and the solar disc kept bisected by the cross-wires until the exact moment 4 p.m. G.M.T., corrected for equation of time and longitude; the lower, limb, circle is then clamped, and all subsequent measures are made by rotating the vernier circle only.

The 0°—180° diameter of the azimuth circle now lies in the meridian of the place of observation, so that when the vernier

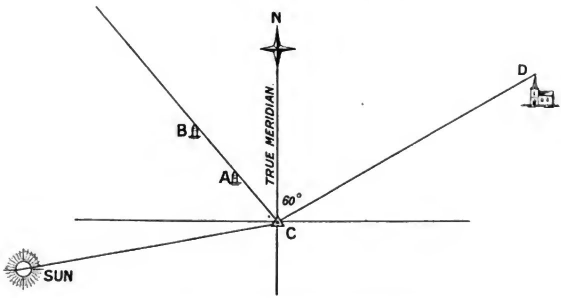


FIG. 37.—Method of Plotting Work, using Burdwood's Tables.

readings are 0° and 180° the telescope is directed to the true N. or S. point.

The azimuths of the objects to be observed may now be read off directly, taking great care not to alter the adjustments or move the lower circle, or the azimuth of a distant fixed object may be determined, once and for all, and this fixed object subsequently used as a permanent reference mark for the complete survey.

The example illustrated in Fig. 37 will show the method of working back on to an alignment when Burdwood's tables are used.

Let A and B represent the stones whose line of bearing is required, and D a distant object. Set up the theodolite at C *with A and B in line*, then clamp the upper plate at zero, and having adjusted the instrument clamp the lower plate on to D, the distant object: then at the time selected for taking the bearing (which has already been obtained from Burdwood's tables) take the angle

between D and the sun by freeing the upper plate: we will call this 200°, and the bearing of the sun N. 100 W. (out of the tables). Therefore the true bearing of D = N. 100 W. + 200° = N. 300 W. or N. 60 E. Now observe the angle from D to AϕB,[1] say it is 260°. Then we have the true bearing of distant object N. 60° E. to which is added, 260° = N. 320° E. or N. 40° W., which is the true bearing of the alignment required.

With regard to the use of Burdwood's Tables generally, it may be added that the observations of the sun should be arranged for, if possible, just after sunrise or just before sunset when the sun's azimuth is altering most slowly. The method of observation described on p. 71 should be used.

[1] In surveying ϕ means "in line with"; so that the angle in question is that subtended at C between the line C D, and the line joining C, A and B.

CHAPTER XIV

OTHER METHODS OF DETERMINING AZIMUTHS

In the following methods a knowledge of the use of mathematical formulæ and logarithms is essential.[1] Special attention must be directed to the spherical triangle ZPS in Fig. 7, which may be termed the "astronomical triangle," and the letters which are generally used in connection with it.

Sides of triangle:—

ZP = Co-latitude (c) = 90°—latitude. (lat., l, λ or ϕ).

ZS = Zenith distance (z) = 90°—altitude (a).

PS = North polar distance ($\triangle$) = 90°—declination (dec. or δ).

Angles:—

ZPS = hour angle (HA, or h).

PZS = Azimuth (Az, or A), reckoned from the N. point towards E. and W. according as the sun or star is E. or W. of the meridian.

PSZ = parallactic angle (p).

Any three of these six quantities being given, the other three can be calculated by the rules of spherical trigonometry.

(1) *By Observations of the Sun or a Star on the Horizon.*—When the sun, or a star of which the declination is known, represented by S in Fig. 7, is on the horizon, and the latitude of the place of observation is also known; if refraction be neglected, the formula

$$\text{Cos A} = \cos \triangle \text{ sec lat.}$$

or

$$\text{Cos A} = \text{sin dec. sec. lat.}$$

at once gives us the azimuth.

[1] They are extracted from *Demonstrations and Practical Work in Astronomical Physics*, prepared under my direction many years ago for the use of my students at the Royal College of Science. It costs 1s., and can be obtained from Messrs. Wyman.

If the elevation of the horizon be about $\frac{1}{2}°$, the result is very nearly true, for the horizon elevation in that case neutralises the effect of refraction. Any star for which the declination is given in the Nautical Almanac (pp. 298—413, 1909) may be used, but as the observation is to be made at the horizon it will probably be found in actual practice that only a few of the brightest stars can be employed. After the azimuth of the sun or star has thus been determined, the position of the N. point and the true bearing of a reference mark can at once be found.

(2) *By Observations of the Sun with Instruments without a Vertical Circle.*—In order to employ this method, correct time and the latitude must be known.

Having adjusted the instrument and set zero of horizontal circle to reference mark, direct the telescope to the sun. Turn the telescope so that the sun is a little behind the vertical wire, and take times of transit of preceding and following limbs by chronometer; read the horizontal circle. Reverse telescope and repeat the operation. Take the mean of the times of transit as corresponding to the mean of the readings of the horizontal circle, and calculate as shown on the form.

The formulæ employed are:—

$$(1)\ \text{Tan M} = \sec h \tan \delta,$$
$$(2)\ \text{Tan A} = \tan h \cos \text{M}, \operatorname{cosec} (\phi - \text{M}),$$

where M is an auxiliary angle introduced for purposes of computation, and h, δ, A and ϕ have the significance given to them on p. 68. Of these, h is the local apparent time derived as shown in the form; δ (declination) is obtained from the Nautical, or Whitaker's, Almanac; A is the quantity we are seeking, and ϕ (latitude) may be read off from the one-inch Ordnance map of the locality. The form on p. 70 may be conveniently used.

This method is useful in the determination of magnetic variation by the use of instruments which are not provided with vertical circles for the measurement of altitudes. The compass bearing of a reference mark, compared with the true bearing derived from the observations, gives the magnetic variation.

FORM A.

Place of Observation ______ Date ______

Latitude (ϕ) ______ Longitude ______

Chronometer ______ Error ______

Observations.

	Time of ☉'s Transit.	Azimuth Circle Readings.	
		Sun.	Reference Mark.
	H. M. S.	° ′ ″	° ′ ″
For Sun: Telescope direct, Preceding limb ...			
Telescope direct, Following limb ...			
Telescope reversed, Preceding limb ..			
Telescope reversed, Following limb ...			
Sums			
Means			
Error of Chronometer			
G. M. T..........			
Equation of Time.........			
Greenwich Apparent Time ..			
Longitude			
Local Apparent Time			
☉'s hour angle = h		L Sec h =	
☉'s declination = δ		,, Tan δ =	

L Tan M =

° ′ ″

M =

ϕ − M =

L Cos M =

L Cosec (ϕ − M) =

L Tan h =

A =

L Tan A =

Mean Circle reading on ☉ =

Meridian reading of Circle =

Circle reading of Reference Mark .... =

Azimuth of Reference Mark =

(3) *By Theodolite Observations of the Sun near the Prime Vertical.*—In this method, having previously found the sun's declination, from the Nautical Almanac, at the time of observation, and knowing the latitude of the place of observation, we have to determine the zenith distance as follows:—

Set the horizontal circle at zero and clamp. With lower clamp and tangent screw set cross-wires on reference mark and fix lower clamp till end of observations.

The position of the sun's centre is determined indirectly by making pairs of observations, as indicated in the accompanying

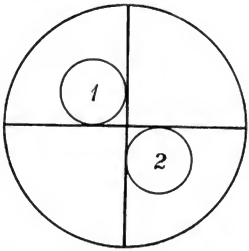


FIG. 38.—Method of observing the Sun on the cross-wires of the Theodolite.

diagram, first with telescope direct, and then with telescope reversed. In the morning, the preceding (western) and upper limbs should be first made tangential to the wires, and then the following (eastern) and lower limbs. In the afternoon, the preceding and lower limbs should be first observed. When making the observations, it is best to move only the fine adjustment in azimuth, keeping the vertical wire tangential with the limb until the image becomes tangential with the horizontal wire. The zenith distance is (90° − the observed altitude + refraction), and the latter may be found from the curve of refractions given on p. 37 or from the Tables of Bessel's refractions given in the Almanac.

The computations may be conveniently made on the following form:—

FORM B.

Observations.

Place of Observation____________________________

Latitude____________________ Date____________________

		Horizontal Circle.	Vertical Circle
		° ′ ″	° ′ ″
For Sun	Telescope direct: Preceding limb.........		limb
	Telescope direct: Following ,, ...		limb
	Telescope reversed: Preceding ,, ...		limb
	Telescope reversed: Following ,, ...		limb
	Sums		
	Means		
	Refraction – =		
	True altitude of ⊙'s centre ...		

Computation.

$$\text{Sin}\tfrac{1}{2}A = \sqrt{\frac{\text{Sin}\tfrac{1}{2}(\Delta + c - z)\quad \text{Sin}\tfrac{1}{2}(\Delta + z - c)}{\text{Sin}\, c \quad \text{Sin}\, z}}$$

	° ′ ″	
North Polar distance of sun ... = Δ		
Co-latitude .... = c		L Cosec
Zenith distance of sun .... = z		L Cosec
$\tfrac{1}{2}(\Delta + c - z)$		L Sin
$\tfrac{1}{2}(\Delta + z - c)$		L Sin

Sum =

L Sin $\tfrac{1}{2}$ A = $\tfrac{1}{2}$ Sum =

$\tfrac{1}{2}$ A =

Azimuth of sun from S $\left\{\begin{array}{l}\text{Aftn.} = 180 - \text{A.}\\ \text{Morn.} = 180 + \text{A.}\end{array}\right\} = a =$

Mean circle reading on sun $= m$ =

Reading of circle at south point = R = $(m - a)$ =

Azimuth of zero and of reference mark = 360° – R =

From the azimuth of the reference mark that of any other point may be obtained or the meridian marked out.

It is by no means essential that the instrument be set to zero on the reference mark, but it simplifies matters for beginners to do so.

(4) *By Observation of Circumpolar Stars.*—In the observation of circumpolar stars for measurement of azimuths it is best to

observe them near their greatest elongations, their movements in azimuth being then very slow. In connection with this the following formulæ are useful :—

$$\cos h = \tan \phi \cot \delta \qquad (1)$$
$$\sin A = \cos \delta \sec \phi \qquad (2)$$
$$\cos z = \sin \phi \operatorname{cosec} \delta \qquad (3)$$
where δ = declination of star.

The sidereal time of greatest elongation is h + R.A.

The general procedure is to calculate the approximate time of the greatest elongation (noting whether east or west of the pole) and to take several readings on the horizontal circle for several minutes before and after this time, when the star is at the intersection of the wires. The extreme reading is that corresponding to the greatest elongation, the true azimuth of which is calculated from the second equation. The reading for the reference mark being taken about the same time, the azimuth of the mark can be easily ascertained. The calculation of the zenith distance of the star by the third equation is a useful aid to finding the star in the telescope.

EXAMPLE.—*Observation of a Ursæ Majoris (Dubhe), December* 21, 1908, in lat. 50° N.

R.A. of star } From Whitaker's Almanac, p. 75, 1908 { = 10h. 58m. 4s.
Decl. of star } { = 62° 14′ 52″ N.

For time of elongation :—

$$\cos h = \tan \phi \cot \delta$$

$\cos h = \tan 50°$ ...	0·076186
$\times \cot 62° 14' 52''$ ...	$\bar{1}$·721130
log cos 51° 9′ 57″ ...	= $\bar{1}$·797316

$$h = 51° \ 9' \ 57''$$
$$= 3\text{h. } 24\text{m. } 40\text{s.}$$

	H.	M.	S.
For western elongation h ...	= 3	24	40
For eastern ,, h ...	= 20	35	20
R.A. ...	= 10	58	4
	31	33	24
	24	0	0
Sidereal time of eastern elongation ...	7	33	24
Sidereal time at preceding noon ...	17	58	37
Sidereal interval from preceding noon ...	13	34	47
Mean time equivalent of 13h. 34m. 47s. sidereal time =	13	32	33

Therefore eastern elongation takes place at 1 32 33 A.M.

For azimuth at elongation :—

$$\sin A = \cos \delta \sec \phi$$

	Logs
$= \cos 62° \, 14' \, 52''$	$\bar{1}\cdot668059$
$\times \sec 50°$	$0\cdot191932$
$\log \sin 46° \, 25' \, 15''$	$\bar{1}\cdot859991$

$$A = \text{N. } 46° \, 25' \, 15'' \text{ E.}$$

Observations and Reduction :—

Greatest reading of star on circle	256°	33′	0″
True azimuth of star	46	25	15
Reading of circle for true north = R.	=210°	7′	45″
True azimuth of zero point = 360° − R	=149	52	15
Reading of Reference Mark	65	28	0
Therefore true azimuth of Reference Mark	=215°	20′	15″

5. *By the Observation of any Star: latitude and declination known and zenith distance measured.*—This method is the same, in principle, as that employed in the sun observation in (3), the only difference occurring in the details of the method of measuring the altitude. In this case, the star image being a point, the altitude of the object in each observation is read off directly. On correcting the mean value for refraction and subtracting from 90° we get the zenith distance as before.

Having determined the zenith distance, the formulæ and form given on p. 72 should be employed in calculating the azimuth.

CHAPTER XV

GENERAL TABULATION OF SOLAR AZIMUTHS

THE archæological surveyor is now in a position to determine his azimuths. In previous chapters we have discussed the changes of azimuth due (1) to the height of the horizon, (2) to the latitude of the place of observation. The facts show very plainly the great variation in azimuth the archæologist has to reckon with when he roams Britain to determine the orientation of his monuments, whether oustanding stone, recumbent stone, avenue or cromlech. It will be convenient if I give here, for the benefit of archæological surveyors, some general diagrams showing the solar azimuths on the critical days of the solstitial and May years in different latitudes and with varying heights of the horizon.

These diagrams are good for the whole of Britain and for part of Brittany, and take varying heights of the horizon into account.

I will begin with the solstices.

The solstitial year is, however, not the only one to be considered. I have shown in "Stonehenge" that the year first used in Britain ran from November to May. It was a "farmer's year," and had a strict connection with the chief agricultural operations in many countries besides Babylonia and Egypt, where apparently it was first regulated, perhaps even before the full meaning of the solstices, or the length of the year, had been made out.

These curves show the azimuths in which the Sun is first seen The declinations employed were ± 23° 30′ and ± 16° 20′ respectively, N. and S. The solstitial values are therefore not correct for ancient times, in consequence of the reduction in the value of the obliquity of the ecliptic (see Fig. 43, p. 89), but they are near enough for a first approximation.

Thus, supposing an observer in lat. 55° N. finds an azimuth of N. 45° 30′ E. (or W.), the elevation of the horizon being ½°, a glance at fig. 39 will show him that he is dealing with a Summer

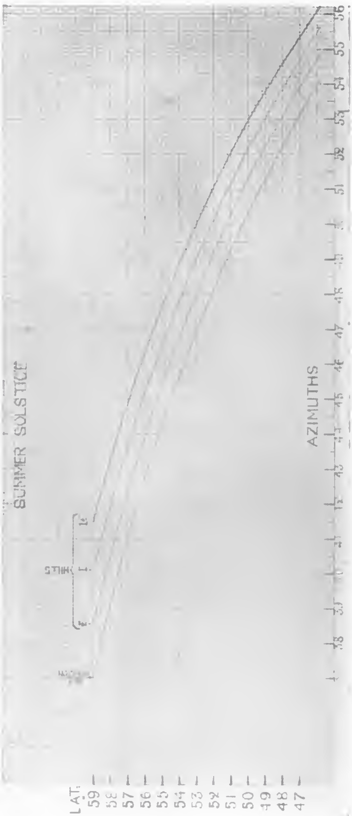


FIG. 39.—The Azimuths of the Sunrise (upper limb) at the Summer Solstice. The values given in the table have been plotted, and the effect of the height of hills on the azimuth is shown. The range of latitude given enables the diagram to be used in connection with the solstitial alignments at Carnac, Le Ménac, and other monuments in Brittany.

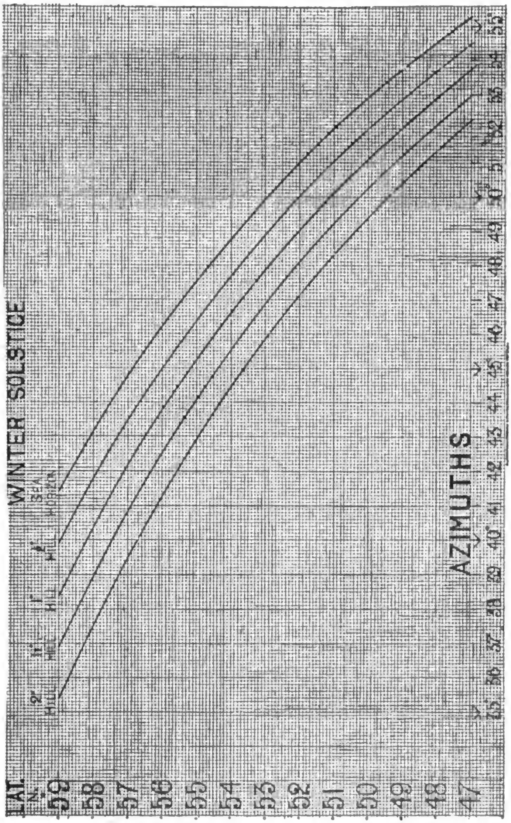


FIG. 40.—Azimuth of Sunrise (upper limb) at Winter Solstice.

Solstice alignment. Similarly fig. 41 would show that an azimuth of N. 61° 20′ E., or W., in the same latitude and with a hill of 1° was a May-Sun alignment.

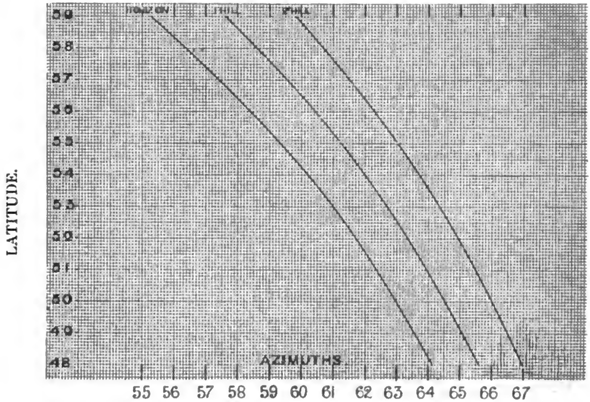


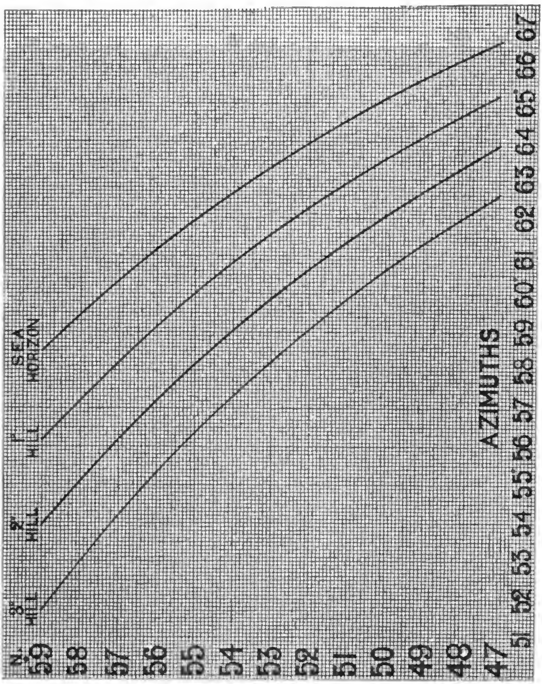
FIG. 41.—Azimuths of the May and August Sunrise. Sun's declination 16° 20′ N.

If the reader will carefully study the various curves and compare them he cannot fail to see the importance of taking the height of the horizon into account in all his measurements. The effect of latitude in changing the azimuth of the sun, and therefore of a star, is shown in an equally practical way.

It will, of course, be understood that whether we deal with the solstitial or the May year sunrises, the azimuth of the sunset is the same as that of sunrise on the same day, but W. instead of E.

This book, of course, is limited to the consideration of the astronomical conditions which have to be taken into account in the measurement of monuments in Britain, but the principles and the method of work with which we have had to deal are, really,

world-wide. If any of my readers wishes to test his or her mastery of what I have written so far, no better exercise could be imagined than the preparation of similar curves for, say, Crete or some region in Asia Minor. The latitude can be got from any atlas, the varia-



LATITUDE.

FIG. 42.—Azimuths of the November and February Sunrise. Sun's declination 16° 20′ S.

tion from the Admiralty charts of the Eastern Mediterranean. The declination of the sun at the solstice and in May, and therefore the N.P.D., are the same there as here.

CHAPTER XVI

SOLAR AZIMUTHS IN VARIOUS TEMPLE FIELDS

It may be convenient to the archæologist to have more special information relating to some of the more important temple fields than that obtainable from the general curves given in the previous chapter, and also to be able to see at once, without calculating in each separate instance, the magnetic readings given by such an instrument as a prismatic compass.

The following tables have therefore been compiled to suit these requirements. The magnetic variation is indicated for each locality, the epoch being in all cases 1907.

Magnetic Solar Azimuths

In all the azimuths given in this table, the effect of refraction has been taken into account, and it has been assumed that 2′ of the sun's vertical diameter is visible at the time of observation.

The values are given to the nearest degree for an angular elevation of the horizon of 0°; the effect of hills of 1° and 2° elevation in various latitudes may be found by reference to the tables of true azimuths given on pp. 81—84.

Locality.	Lat. N.		Theoretical magnetic azimuths at sea horizon.			
			May sun	November sun.	Summer solstice.	Winter solstice.
	°	′	°	°	°	°
Cornwall .... [Variation (1907) 18° W.]	50	30	81	133	68	146
Stonehenge and Avebury......... . [Variation (1907) 16° 50′ N.]	51	30	79	132	66	145
South Wales .... [Variation (1907) 18° W.]	51	30	80	134	67	146
Mid-Wales .... [Variation (1907) 17° 30′ W.]	52	30	79	134	65	147
Anglesea .... [Variation (1907) 18° 36′ W.]	53	15	79	135	65	149
Dublin ... . [Variation (1907) 19° 30′ W.]	53	20	80	136	66	150
Aberdeenshire................. .. ... [Variation (1907) 18° 45′ W.]	57	0	76	138	60	154
Stenness .... [Variation (1907) 19° 20′ W.]	59	0	75	141	56	158

TRUE SOLAR AZIMUTHS.

CORNWALL. Variation 18° W. (1907) Lat. 50° 30′ N.

Theoretical solar azimuths.

Alignment and conditions.	Elevation of horizon.		
	0°.	1°.	2°.
	° ′	° ′	° ′
May sun: sun's limb (2′); refraction ...	N. 62 40 E.	N. 64 15 E.	N. 65 45 E.
November sun: sun's limb (2′); refraction...	S. 64 51 E.	S. 63 15 E.	S. 61 42 E.
Summer solstice: sun's limb (2′); refraction	N. 49 50 E.	N. 51 40 E.	N. 53 18 E.
Winter solstice: sun's limb (2′); refraction	S. 52 27 E.	S. 50 36 E.	S. 48 51 E.

SOUTH WALES. Variation (1907) 18° W.
STONEHENGE. ,, ,, 16° 50′ W. } Latitude 51° 30′ N.
AVEBURY. ,, ,, 16° 50′ W.

Theoretical solar azimuths.

Alignment and conditions.	Elevation of horizon.		
	0°.	1°.	2°.
	° ′	° ′	° ′
May sun : sun's limb (2′) ; refraction..	N. 62 3 E.	N. 63 40 E.	N. 65 13 E.
November sun : sun's limb (2′) ; refraction	S. 64 16 E.	S. 62 36 E.	S. 61 0 E.
Summer solstice : sun's limb (2′) ; refraction	N. 48 44 E.	N. 50 40 E.	N. 52 24 E.
Winter solstice : sun's limb (2′) ; refraction	S. 51 30 E.	S. 49 40 E.	S. 47 44 E.

MID-WALES. Latitude 52° 30′ N. Mean variation 17° to 18° W. (1907).

Theoretical solar azimuths.

Alignment and conditions.	Elevation of horizon.		
	0°.	1°.	2°.
	° ′	° ′	° ′
May sun : sun's limb (2′) ; refraction ...	N. 61 24 E.	N. 63 0 E.	N. 64 27 E.
November sun : sun's limb (2′) ; refraction	S. 63 40 E.	S. 61 56 E.	S. 60 15 E.
Summer solstice : sun's limb (2′) ; refraction	N. 47 33 E.	N. 49 33 E.	N. 51 37 E.
Winter solstice : sun's limb (2′) ; refraction	S. 50 27 E.	S. 48 27 E.	S. 46 28 E.

DUBLIN. Variation 19° 30′ W. (1907). Latitude 53° 21′ N.
ANGLESEA. „ 18° 36′ W. „ „ 53° 15′ N.

Theoretical solar azimuths.

Alignment and conditions.	Elevation of horizon.		
	0°.	1°.	2°.
	° ′	° ′	° ′
May sun : sun's limb (2′) ; refraction .	N. 60 48 E.	N. 62 32 E.	N. 64 12 E.
November sun : sun's limb (2′) ; refraction	S. 63 9 E.	S. 61 24 E.	S. 59 40 E.
Summer solstice : sun's limb (2′) ; refraction	N. 46 40 E.	N. 48 45 E.	N. 50 36 E.
Winter solstice : sun's limb (2′) ; refraction	S. 49 40 E.	S. 47 34 E.	S. 45 32 E.

ABERDEENSHIRE. Variation 18° 45′ W. (1907). Latitude 57° N.

Theoretical solar azimuths.

Alignment and conditions.	Elevation of horizon.		
	0°.	1°.	2°.
	° ′	° ′	° ′
May sun : sun's limb (2′) ; refraction ...	N. 57 24 E.	N. 59 33 E.	N. 61 30 E.
November sun : sun's limb (2′) ; refraction	S. 60 20 E.	S. 58 12 E.	S. 56 10 E.
Summer solstice : sun's limb (2′) ; refraction	N. 41 0 E.	N. 43 39 E.	N. 46 0 E.
Winter solstice : sun's limb (2′) ; refraction	S. 44 45 E.	S. 42 9 E.	S. 39 27 E.

STENNESS. Variation 19° 20′ W. (1907). Latitude 59° N.

Theoretical solar azimuths.

Alignment and conditions.	Elevation of horizon.		
	0°.	1°.	2°.
	° ′	° ′	° ′
May sun: sun's limb (2′); refraction ...	N. 55 15 E.	N. 57 37 E.	N. 59 50 E.
November sun: sun's limb (2′); refraction	S. 58 30 E.	S. 56 9 E.	S. 53 55 E.
Summer solstice; sun's limb (2′); refraction	N. 37 0 E.	N 40 6 E.	N. 43 0 E.
Winter solstice: sun's limb (2′); refraction	S. 41 24 E.	S. 38 22 E.	S. 35 24 E.

The tables should be found of great service in the field work. For the localities with which they deal they show at a glance the directions in which to look for the several solar alignments, and settle at once whether any observed value is approximately of a solar character.

The inclusion of the magnetic variation for each place of observation will enable the observer to refer directly to magnetic azimuths, but it must be borne in mind that whilst these values are approximately correct for 1907 they will not be correct for the succeeding years owing to the secular variation; at present for any one station in the British Isles the value of the magnetic declination is decreasing by between 4′ and 5′ per annum.

CHAPTER XVII

DETERMINATION OF DECLINATION FROM AZIMUTHS

WHEN the archaeologist has obtained the various azimuths he requires in the consideration of any monument, the next problem in front of him is to find the declination of the heavenly body, whether sun or star, which rose or set in the azimuths of his sight lines when the monument was erected.

As a great majority of the sight lines so far investigated have to do with sunrise on the critical dates of the solstitial or May year, or at certain times before, so as to be used as warners, I will deal with the sun first, remarking that when the azimuth of the sight line has once been determined a reference to Fig. 35 will at once show by the corresponding declination in the latitude of the place of observation whether the declinations about 23° 30′ or 16° 20′ North or South are involved; if so, the probability is that we are dealing with a solar alignment.

Now the conditions of sunrise and star-rise are widely different. A star appears as a point, the sun as a disc with, let it be added, a diameter of 32 minutes of arc and therefore with a semi-diameter of 16′. The declination of the sun given in almanacs for any day is the declination of a point at its centre; it is treated as the other stars.

There is every reason to believe that in ancient times it was the appearance of the edge of the sun's disc that was hailed as the beginning of the new day and, at the most solemn festivals, of the new year. It was not a question of waiting till the sun was half risen at which time its centre was on the horizon.

Hence in all the subsequent sunrise tables—and the same considerations hold good for sunset—I have dealt, not with the

sun's centre, but with the point 14′ from the centre, rising as the sun's limb was becoming visible.

This premised, let us see how azimuth is transformed into declination.

The process of calculating the declination will be gathered from the example given below :—

Data.

Monument :—E. circle Tregeseal. lat. 50° 8′ N. *i.e.* colat. = 39° 52′.

Alignment. Centre of circle to Longstone.

Az. (from 25 inch Ordnance Map). N. 66° 38′ E.

Elevation of horizon (measured) 2° 10′.

A reference to the curve (Fig. 41) given on p. 78 indicates that this is probably an alignment to the sunrise on May morning.

We will deal with it, therefore, as a sun alignment, and in determining the zenith distance, which has to be found in the first instance, the correction for the sun's semi-diameter must be taken into account, allowing that 2′ of the sun's disc was above the horizon when the observation was made; the correction amounts to 14′.

Zenith distance of true horizon	. . . . .		=	90°
„ „	local „	= 90° − 2° 10′	=	87° 50′

Bessel's tables (Fig. 28) show that refraction, at altitude 2° 10′, raises sun 17′. If 2′ of sun's limb is above horizon, sun's centre is 14′ below.

∴ True zenith distance of sun's centre = 87° 50′ + 17′ + 14′ = 88° 21′.

Having obtained the zenith distance, the azimuth and the latitude being known, the N.P.D. (North Polar Distance) of the sun may be found by the following equations :—

(1) $$\tan\theta = \tan z. \cos A.$$

where θ is the subsidiary angle which must be determined for the purpose of computation; z is the true zenith distance, and A is the distance from the *North* point, that is, the azimuth.

(2) $$\cos\Delta = \frac{\cos z. \cos(c-\theta)}{\cos\theta}\text{[1]},$$

where Δ is the N.P.D. of the celestial object, and c is the colatitude (90° − lat.) of the place of observation.

[1] $\cos(c-\theta) = \cos -(c-\theta)$.

In the example taken this gives us, inserting values—

$$(1) \qquad \tan \theta = \tan 88^\circ\ 21' \cos 66^\circ\ 38'$$

$$\theta = 85^\circ\ 50'\ 45''$$

$$(2) \quad \cos \Delta = \frac{\cos 88^\circ\ 21'.\ \cos (39^\circ\ 52' - 85^\circ\ 50'\ 45'')}{\cos 85^\circ\ 50'\ 45''}$$

$$\Delta = 73^\circ\ 57'\ 50''$$

$$\text{Declination, } \delta, = (90^\circ - \Delta) = 16^\circ\ 2'\ 10''\ \text{N.}$$

Reference to the Nautical Almanac shows that this is the sun's declination on May 5 and August 9. We may therefore conclude that the Longstone was erected to mark the May sunrise, as seen from the Tregeseal Circle.

The declination of a star is found in precisely the same way; the only modification necessary in calculating the declination is to omit the semi-diameter correction of 14′.

We may take as an example the case of star-rise as seen along the avenue at Fernworthy. The data are:—

Az. N. 15° 45′ E., hill = 1° 15′, latitude = 50° 38′.

Such a high northern azimuth tells us at once that we cannot be dealing with the sun.

Working as before, we obtain a declination of 38° 34′ N., and a reference to the curves (Fig. 47) shows us that we are probably dealing with an alignment to Arcturus, as a clock-star, in 1610 B.C.

In cases where the elevation of the horizon is 30′, or in preliminary examinations, where it may be assumed as 30′, the refraction counterbalances the hill, and therefore the true zenith distance at the moment of apparent star-rise is 90°. Hence the N.P.D. of the star may be found from the following simple equation:—

$$(3) \qquad \cos \Delta = \cos A \cos \phi,$$

where Δ and A have the same significance as before, and ϕ is the *latitude* of the place of observation. It may be noted that here we perform the reverse operation to that given on p. 68. There, having the N.P.D. (Δ) and the latitude (ϕ), we calculated the azimuth (A); in this case, having measured the azimuth and knowing the latitude, we calculate the N.P.D. by the same formula transposed, and the N.P.D. is the complement of the declination which is the value we seek.

CHAPTER XVIII

THE FINDING OF DATES BY SOLSTITIAL ALIGNMENTS

In the astronomical study of ancient monuments, the archæologist's measures of azimuth and altitude enable him to determine the declination of the celestial bodies the rising and setting places of which are indicated by the direction of avenues or of outstanding stones seen from the centre of a circle.

But this, after all, is but the means to an end; it is only a first step.

The second step is to find, *if possible*, from the declinations, the dates at which the sun or a star occupied these declinations. This date gives us the time at which the "ancient" stone monument was set out, and because the monument is an ancient one it is certain that the declination of the sun at a solstice and of the stars were different from what they are now. I will deal with the sun first.

In consequence of causes which need not be gone into here, the angle between the plane of the earth's equator and of the ecliptic —called the obliquity of the ecliptic—is getting smaller. For this reason the sun's declination at a solstice, which defines the value of the obliquity, is less now than it was in times past.

This rate of change is very slow, as will be gathered from the diagram—Fig. 43—a little more than half a degree in 4000 years. The present value is 23° 27′; in 1680 B.C., the date of the erection of the sarsens at Stonehenge, according to the measures made by Mr. Penrose and myself, it was 23° 55′.

Now in these latitudes this change of half a degree in

declination produces a greater change in the azimuth. In Fig. 30 I gave not only the solstitial azimuth at the present day, in lat. 50° N., but also that of 1680 B.C. It will be seen that there is nearly a difference of one degree; still, this is not very much considering stone monument conditions.

Hence, in attempting to deduce a definite date from a solstitial alignment, favourable conditions of the monument, such as the avenue at Stonehenge, and exceedingly careful observations are

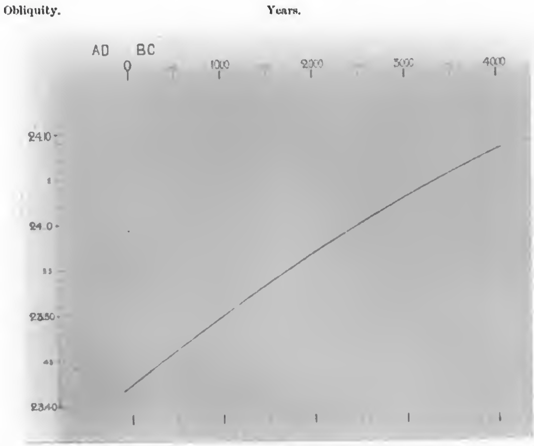


FIG. 43.—Variation of the Obliquity of the Ecliptic, 100 A.D.–4000 B.C. (Stockwell's Values.)

absolutely essential. Any others are practically valueless, because, as will be gathered from the curve, an error of only 10′ in the derived declination produces an error of some 1300 years in the date.

It is only the solstitial alignment that can help us, in consequence of the sun then arriving at the extreme declination. An equinoctial alignment is of no use, because with any value of obliquity the sun's declination at the equinox is always 0°.

From May–November alignments it is impossible to derive any date, owing to the rapidity with which the sun's declination

changes at those seasons of the year—more than a quarter of a degree each day Speaking generally, then, it is *not possible* to determine an accurate date for solar alignments.

The only serious attempt so far to derive a date by an alignment to the solstice, using the change in the obliquity of the ecliptic, was made by Mr. Penrose and myself at Stonehenge, taking

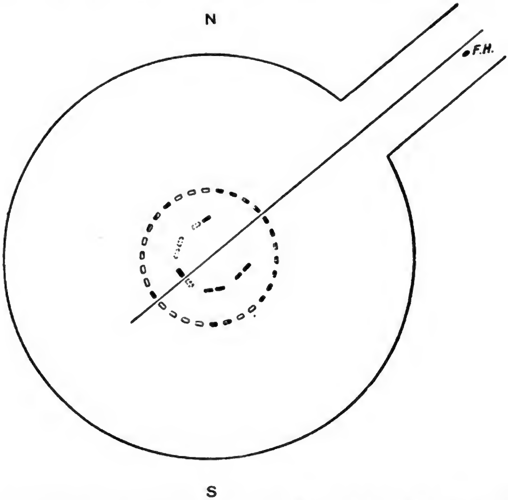


FIG. 44.—General Plan of Stonehenge, the Outer Circle, Naos and Avenue; F.H. = Friar's Heel.

advantage of the well marked avenue; it is to be hoped that as our knowledge of the monuments increases other alignments as definite as the avenue at Stonehenge will be found.

The conditions of observation at Stonehenge will be gathered from Fig. 44, in which the line drawn through the centres of the naos, circle and vallum, and passing to the north of the Friar's Heel, represents the common direction of the avenue and of the axis of the temple.

It may be useful to give in this place the actual observations

made at Stonehenge, so that an idea of the actual work necessary in such inquiries may be gathered.

The instrument chiefly employed was a six-inch transit theodolite by Cooke with verniers reading to 20″ in altitude and azimuth. Most of the observations were made at two points very near the axis, which may be designated by *a*, *b*. Station *a* was at a distance of 61 feet to the south-west of the centre of the temple, and *b* 364 feet to the north-east. The distance from the centre of Stonehenge to Salisbury Spire being 41,981 feet, the calculated corrections for parallax at the points of observation with reference to Salisbury Spire are:—

Station *a* + 4′ 12″.
„ *b* − 25 20.

(1) *Relative Azimuths.*—Theodolite at station *a*—using Salisbury Spire as a reference mark.

Salisbury Spire	0°	0′	0″
N. side of opening in N.E. trilithon of the external ring..................	237	27	40
Tree in middle of clump on Sidbury Hill	237	40	20
Highest point of Friar's Heel.........	239	47	25
S. side of opening in N.E. trilithon...	240	14	40
Middle „ „ „ ...	238	51	10

(2) *Absolute Azimuths.*—All the azimuths were referred to that of Salisbury Spire, the azimuth of which was determined by the following observations of the Sun and Polaris:—

(*a*) *Observation of Sun, June* 23, 1901, 3.30–3.40 P.M.

Mean of observed altitudes of Sun		41°	26′	35″
Refraction	− 1′ 4″	0	0	58
Parallax	+ 6			
True altitude of Sun's centre ...		41	25	37

Latitude = 51° 10′ 42″. Sun's declination = 23° 26′ 43″.

Using the formula

$$\cos^2 \tfrac{1}{2}A \quad \frac{\sin \frac{1}{2}(\Delta + c - z) \sin \frac{1}{2}(\Delta + z - c)}{\sin c \,.\, \sin z},$$

where A = azimuth from south, Δ = polar distance, c = co-latitude, and z = zenith distance,

we get

Azimuth of Sun........................	S. 75°	30′	30″	W.
Mean circle reading on Sun.........	84	38	35	
Azimuth of Salisbury Spire.........	S. 9	8	5	E.

(*b*) *Observations of Polaris.*—June 23, 1901. Time of greatest easterly elongation, calculated by formula $\cos h = \tan \phi \cot \delta$, is G.M.T. 1.34 A.M.

Azimuth at greatest easterly elongation, calculated by the formula

$$\sin A = \cos \delta \sec \phi,$$

is 181° 57′ 0″ from south.

Observed maximum reading of circle......	256°	33′	0″
True azimuth of star...........................	181	57	0
Meridian (S.) reading of circle...............	74	36	0
Circle reading on Salisbury Spire	65	28	0
Azimuth of Salisbury Spire...S.	9	8	0 E.

The mean of the two determinations gives for the azimuth of Salisbury Spire S. 9° 8′ 2″ E. This result agrees well with the value of the azimuth communicated by the Ordnance Survey Office, namely, 9° 4′ 8″ from the centre of the circle, which being corrected by + 4′ 12″ for the position of station *a*, is increased to 9° 8′ 20″.

Hence, from the point of observation *a*, 9° 8′ 20″ has been adopted as the azimuth of Salisbury Spire.

We thus get the following absolute values of the principal azimuths from the point *a*:—

Highest point of Friar's Heel	239°	47′	25″	
	−9	8	20	
	230	39	5	
or N.	50	39	5	E.
Middle of opening in N.E. trilithon......	238	51	10	
	−9	8	20	
	229	42	50	
or N.	49	42	50	E.

The difference of $8\frac{1}{2}'$ between this and the assumed axis 49° 34′ 18″ is so slight, that considering the indirect method which has necessarily been employed in determining the axis of the temple from the position of the leaning stone, and the want of verticality, parallelism and straightness of the inner surfaces of the opening in the N.E. trilithon, we are justified in adopting the azimuth of the avenue as that of the temple.

Next, with regard to the determination of the azimuth of the avenue as indicated by a line of pegs carefully placed in the centre. The small angle between the nearest pegs A and B (which are supposed to be parallel to the axis of the avenue), observed from station *a*, was measured, and the corresponding calculated correction was applied to the ascertained true bearing of the more distant peg B.

Thus

True bearing of peg B=	238°	35′	0″
Calculated correction to peg A= ...	0	12	8
True bearing of line AB	238	47	8
Bearing of Salisbury Spire	189	8	20
True bearing of a line parallel to the axis of near part of avenue.........N.	49	38	48 E.

The mean of the three independent determinations by another observer was 49° 39′ 6″.

The calculated bearing of the more distant part of the axis of the avenue determined in the same manner by observations from station *b* is 49° 32′ 54″. The mean of the two, namely, 49° 35′ 51″, justifies the adoption of the value 49° 34′ 18″ as given by the Ordnance Survey for the straight line from Stonehenge to Sidbury Hill.

(3) *Observation of Sunrise.*—On the morning of June 25, 1901, sunrise was observed from station *a*, and a setting made as nearly as possible on the middle of the visible segment as soon as could be done after the Sun appeared.

The telescope was then set on the highest point of the Friar's Heel, and the latter was found to be 8′ 40″ south of the Sun.

Sun's declination at time of observation	23°	25′	5″
Elevation of horizon at point of sunrise...	0	35	48
Assuming 2′ vertical of Sun to have been visible at observation, we have apparent altitude of Sun's upper limb	0	37	48
Refraction........ ......−27′ 27″ Parallax..................+ 0 9	−0	27	18
True altitude of upper limb	0	10	30
Sun's semi-diameter	0	15	46
True altitude of Sun's centre	−0	5	16
From this it results that the true azimuth of the Sun at the time of observation =N.	50°	30′	54″ E.
And since azimuth of Friar's Heel......=	50	39	5
2′ of sunrise should be N. of Friar's Heel	0	8	11
Observed difference of azimuth ....=	0	8	40
Observed—calculated ....=	0	0	29

The observation thus agrees with calculation, if we suppose about 2′ of the Sun's limb to have been above the horizon when it was made, and therefore substantially confirms the azimuth above given of the Friar's Heel and generally the data adopted.

CHAPTER XIX

THE FINDING OF DATES BY STELLAR ALIGNMENTS

IN Chapter XVII I showed how with certain data, including a measured azimuth and altitude, the declination of the star which rose on the alignment indicated by the monument can be found. Having this declination, the next step is to inquire which star occupied that position in times past, and *when.*

In dealing with stars, the problem of finding a date is much more within the possibility of observation than in the case of the sun. The stars change their declination 47° in 25,800 years, that is, 1° in 550 years on the average, and some stars at some times change it much more rapidly.

This relatively very great change in the declination of stars from century to century is brought about by the action of the sun and moon on the earth's motion.

The action referred to does not depend upon the actual attractions of the sun and moon upon the earth as a whole, which are in the proportion of 120 to 1, but upon the difference of the attraction of each upon the earth's bulge at the equator, arising from the fact that the equatorial diameter is the larger. As the sun's distance is so great compared with the diameter of the earth the differential effect of the sun's action is small; but, as the moon is so near, it is so considerable that her precessional action is three times that of the sun.

An important result of the action on the protuberance has now to be considered. The change in the position of the equator caused by the attraction is brought about by a rolling motion, which is necessarily accompanied by a change in the earth's axis.

In Fig. 45, *ab* represents the plane of the ecliptic, CQ a line perpendicular to it, *hfe* the position of the equator at any time at which it intersects the plane of the ecliptic in *e*. The position of the earth's axis is in the direction C*p*. When, by virtue of the rolling or precessional movement, the equator has taken up the position *lkg*, crossing the plane of the ecliptic in *g*, the earth's axis will occupy the position C*p'*.

The lines C*p* and C*p'* have both the same inclination to CQ. It follows, therefore, that the motion of the earth's axis due to

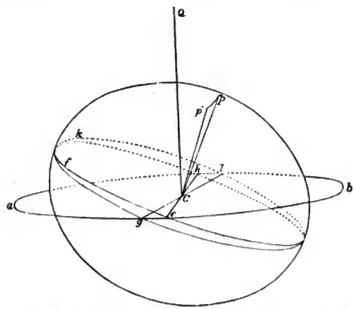


FIG. 45.—Showing the effects of precession on the direction of the earth's axis.

precession consists in a slow revolution round the axis of the celestial sphere, perpendicular to the plane of the ecliptic. During this movement, while the inclination of the two planes remains nearly 23½°, the position of the celestial pole, and consequently our Pole Star, are constantly changing.

An ordinary celestial globe represents the right ascensions and declinations of stars at some epoch near our own time, but some years ago I devised a globe in which the changes brought about by this precessional movement can be shown in a very concrete manner, so that the changes in position can be readily understood.

The precessional globe, as I called it, is, in fact, arranged so that the position of the celestial pole and equator, and consequently the positions of the stars, may be represented at any epoch. In the globe pivots are provided so that it may be turned on the pole of

the ecliptic; round these at a radius of 23½° are brass circles (one of which is shown), with holes in them, each of which may also be used as a pivot. One pair of pivots on the latter circles corresponds to the present celestial poles, and represents the heavens as they are at the present time; the globe is arranged to turn on

FIG. 46.—The Precessional Globe. A, Pole of ecliptic: B, brass circle, with holes on positions of celestial poles at different epochs; C, screw pivot for N. pole of ecliptic; D, screw pivot for N. celestial pole at different epochs; E, scale of years denoting position of celestial pole at definite epochs (set for 1364 B.C.); F–G, brass meridian; H, wooden horizon; J, ecliptic; K, celestial equators drawn for different epochs.

these, the ecliptic pivots being thrown out of gear. Other pivots on the brass circles correspond to other dates, the whole circle being traversed in about 25,800 years. For example, if we wish to set the globe to represent the conditions 2,000 years ago, we first swing the globe on the poles of the ecliptic, then turn it until

the desired points on the brass circle are brought under the other pivots. These are then screwed into position and the first two are freed.

There is a brass meridian passing round the globe at right angles to the horizon, which is graduated as in the ordinary celestial globe.

Several astronomers, including the late Mr. Hind, Dr. Danckwortt, Dr. Lockyer, and Mr. Stockwell, have occupied themselves in calculating the right ascensions and declinations occupied by stars in past times.[1]

Curves have been prepared, and are given here, which show the changing declination of the brightest stars—and declination is the component of a star's position of greatest importance to the archæologist—from 250 A.D. to 2150 B.C.

The numbers on the curves refer to the following stars:—

No.	Name of Star.	No.	Name of Star.
1.	β Ursæ Minoris.	14.	α Coronæ Borealis.
2.	α Ursæ Minoris (Polaris).	15.	α Geminorum (Castor).
3.	α Draconis.	16.	β Geminorum (Pollux).
4.	α Ursæ Majoris (Dubhe).	17.	α Boötis (Arcturus).
5.	γ Ursæ Majoris.	18.	β Leonis.
6.	η Ursæ Majoris (Benetnasch).	19.	α Leonis (Regulus).
7.	γ Draconis.	20.	α Andromedæ.
8.	β Cassiopeiæ.	21.	η Tauri (Alcyone).
9.	α Cassiopeiæ.	22.	α Tauri (Aldebaran).
10.	α Persei.	23.	α Canis Minoris (Procyon).
11.	α Aurigæ (Capella).	24.	α Aquilæ.
12.	α Cygni.	25.	α Orionis (Betelgeuse).
13.	α Lyræ (Vega).	26.	α Virginis (Spica).

A glance at the curves will show that the same declination is occupied by different stars at different dates; hence it may happen that the declination found fits more than one star within probable date limits, and so we have to decide which is the more likely star to have been observed. It might at first sight seem that it would be difficult to settle which star is really in question. But in practice the difficulty does not often arise. We now know that the stars used were those in high northern or southern declinations for noting the time at night in the way the Egyptian temples have familiarised us with, and stars nearer the equator to serve as "morning stars," warners of sunrise.

[1] Dr. Danckwortt's results are given in the *Vierteljahrschrift der Astronomischen Gesellschaft*, 16 Jahrgang, 1881, p. 9. Dr. Stockwell's results have been communicated to me by letter. Some, but not all, of Dr. Lockyer's calculations were used in the *Dawn of Astronomy*.

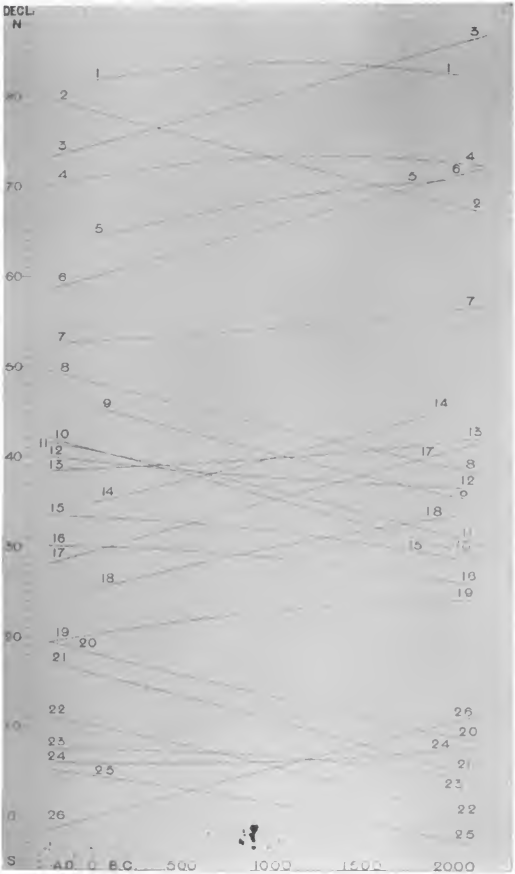


FIG. 47.—Declinations of Northern Stars from 250 A.D. to 2150 B.C.

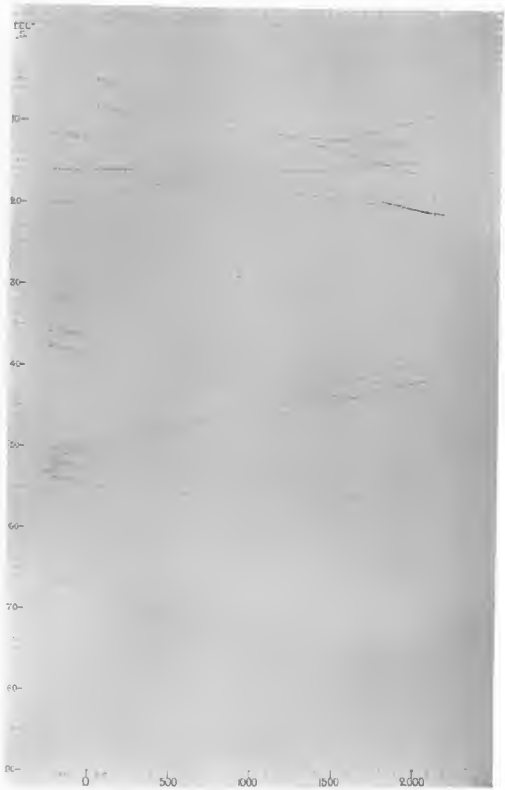


FIG. 48.—Declinations of Southern Stars from 250 A.D. to 2150 B.C. α Ceti, α Aquarii, β Orionis, α Capricorni, α Canis Majoris, α Scorpii, α Columbæ, α Pisces Austr., η Argûs, α Centauri, α Argûs, α Crucis, α Gruis, and α Eridani.

Should one of the stars fitting our declination be much brighter than the others, we may accept it as being the more likely object for the early astronomers to have chosen for observation.

We may also find that one of the stars is included in the list of warning, or morning, stars given in "Stonehenge" near the epoch found for it from the declination value. The morning star was so named because it rose an hour or so before the sun at a crucial season of the year, thus warning the astronomer-priest to prepare for the sunrise ceremonies.

The stars with about the dates already revealed by the work of the last few years may certainly be considered in the first instance, and it is really not a remarkable fact that so few stars are in question, for the use made of them was very definite. Capella, Arcturus, *a* Centauri, the Pleiades and Antares almost exhaust the list.

The use of the precessional globe saves many intricate and laborious calculations when only an approximation is required. Thus warning stars at any quarter of the May or solstitial year, at any given date, may be found by rectifying the globe for the latitude of the place of observation, marking the equator at that date by a circle of water-colour paint by holding a camel's-hair pencil at the east point of the wooden horizon and rotating the globe. The intersection of the equator and the ecliptic gives us the equinoxes at that date, their greatest separation the solstices. With these data we can mark the required position of the sun on the ecliptic.

This done, if we rotate the globe so as to bring the sun's place 10° below the upper surface of the wooden horizon, the rising star which can be used as a warner will be seen on the horizon.

Nor does the use of the globe end here. With a given azimuth—azimuths are marked on the wooden horizon—the globe may be adjusted to different dates and then rotated until at a certain date a star rises at that azimuth.

If the observer is investigating a number of monuments, having similar alignments, in nearly the same latitude, it will be found convenient in a preliminary reconnaissance to have prepared beforehand a set of curves similar to that shown in Fig 49, which are actually used in the investigation of the Aberdeen circles with clock-star alignments. The first thing is to determine the

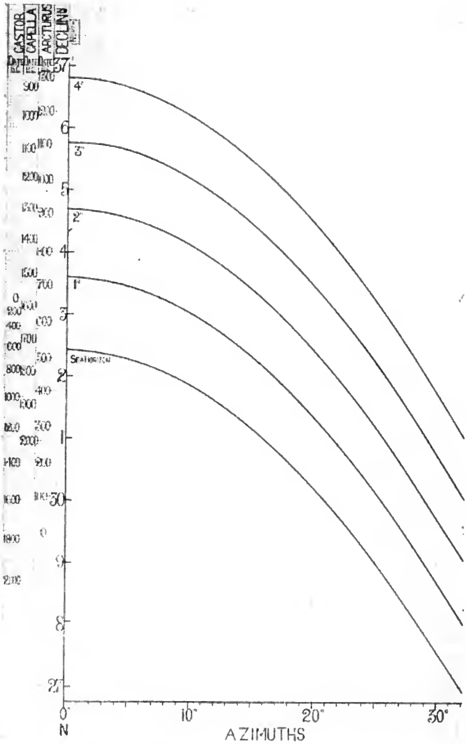


FIG. 49.—Reconnaissance Chart for Clock-star Alignments at Aberdeen (lat. 57° N.).

declinations corresponding to high northern alignments in the latitude of the place where observations are to be made. Next we may draw a curve for a sea horizon showing the change of azimuth with change of declination.

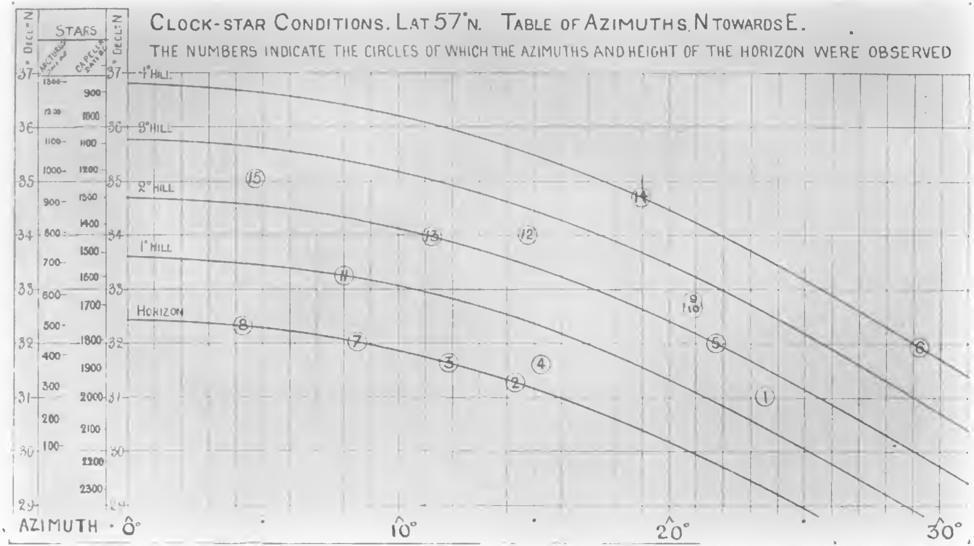


FIG. 50.—Showing the Azimuths and Height of Horizon of the Clock-star Alignments in Aberdeenshire. The numbers in the circles refer to the monument investigated.

Next we require similar curves for different heights of the horizon (decreased zenith distance).

Finally we note at the side the stars which have the declinations we have to deal with, and the dates at which they occupied these declinations. This gives us a chart similar to Fig. 49.

Having this chart, all we have to do when the observations are being made is to locate on it at the proper azimuth and height of horizon the conditions at each monument. The completed result is shown in Fig. 50.

CHAPTER XX

WORK OUTSIDE BRITAIN

1. *Field Work.*

So far in this book I have dealt with British Monuments. It now remains for me to indicate very generally how the various methods of work referred to may be applied in various latitudes outside Britain, especially if the ancient temple fields of Babylon and Egypt and of the classical age in Greece, Crete, and Asia Minor come under consideration. Let us suppose that a site in one of these regions is about to be investigated and that the archæologist proposes to include in his programme a study of the orientation of any alignments whether of temples or avenues he may come across. The work already done in Egypt and Britain makes it fair to assume that these alignments will be solar or stellar, the former referring to the May or solstitial year festivals, the latter for the most part to stars rising not far from the N. or S. points ; but the Pleiades and other warning stars may also be involved.

The astronomical investigation of the monuments in any area will be greatly simplified if the observer equips himself beforehand with a series of reconnaissance curves such as those shown in Chap. XV for Britain. Having such a series it is only necessary to make rough preliminary measures of the azimuths in order to find at once which, if any, of the alignments are in question.

The preparation of such curves is by no means a difficult matter and may perhaps be best illustrated by taking a definite example. We will suppose that the observer is about to investigate the monuments in a region in lat. 37°30′ N.

The solar curves will deal with the solstices (declination 23°30′

N. or S.) and the critical seasons of the May-year (declination 16°20′ N. or S.), whilst of stars, Arcturus, Capella, the Pleiades, and *a* Centauri will probably be sufficient to meet the majority of cases. These stars are those which, as we have seen, were chiefly employed in Egypt and Britain.

To complete these curves for any area we must have as data, (1) the latitude of the place of observation (2) the declination of the sun, or star, and (3) the zenith distance.

In latitude 37°30′ N., the co-latitude (c), the quantity with which we deal in the formula (p. 72), is $90° - 37°30' = 52°30'$. If in our example we deal with the May-sun the declination involved is 16°20′ N., the N.P.D. (Δ) therefore is $90° - 16°20' = 73°40'$. As we are proposing to prepare curves which will show the different azimuths for different elevations of the horizon, in order that the zenith distance may be determined (see figs. 29 and 30) it (z) must be compensated for each elevation thus:—

Zenith distance of sun's centre, on true horizon, refraction neglected	=90°
Therefore zenith distance of sun's centre, when limb (2′ showing), is on horizon, refraction neglected	=90°14′
Refraction apparently raises sun 35′ at the horizon, therefore when sun is first seen it is really 35′ below horizon, *i.e.* zenith distance is 90° 14′+35′	=90°49′

If the sun is rising over a 1° hill the zenith distance of its centre is, similarly, 89°38′, because the refraction at an altitude of 1° is 24′. $89° + 14' + 24' = 89°38'$. For the zenith distance of a star the procedure is the same, except that the correction (14′) for semi-diameter is omitted.

In the following table the zenith distances of the sun and stars with elevations of the horizon up to 3° for the given latitudes are stated:

Elevation of horizon	Zenith for	
	Sun	Star
° 0	° 90 49′	° 90 35′
½	90 13	89 59
1	89 38	89 24
1½	89 5	88 51
2	88 32	88 18
2½	88 0	87 46
3	87 28	87 14

Example.—Compute the azimuths of the May-sun in latitude 37°30′ N., elevation of horizon 0°.

Data.—co-latitude $(c) = 52°30'$.
zenith dist. $(z) = 90°49'$.
N.P.D. $(\Delta) = 73°40'$.

Formula.—The formula given on p. 72 may be employed. The azimuth of the sunrise on May morning (May 6) is then found to be N. 68°34′ E. Similar calculations with the different zenith distances given in the table on p. 106 give azimuths for different elevations of the horizon, from which the observer may prepare a diagram for the given latitude similar to that here given for lat. 50° N.

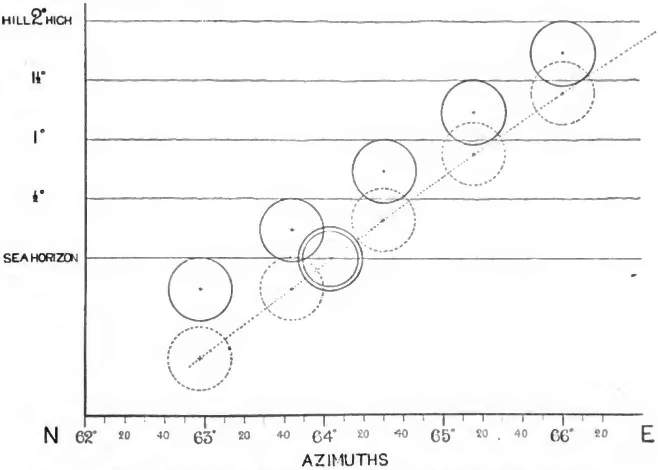


FIG. 51.—Showing the influence of the height of the sky-line on the apparent place of sunrise in May and August in Lat. 50° N. The double circle shows the tabular place of sun's centre.

By taking 23°30′ N. for the declination (*i.e.* N.P.D. 66°30′), instead of 16°20′ N., we obtain the summer solstitial azimuths necessary for the preparation of a diagram similar to that given, for lat. 50 N. in Chap. VII.

To calculate the azimuths for the corresponding November-sun and Winter-solstice diagrams the method of procedure is exactly the same, except that we must remember that *north polar distance*, *not* simply distance from either pole, is to be employed; this gives us, for the values of Δ, $106°20'$ $(90°+16°20')$ and $113°30'$ $(90+23°30')$, respectively. Having plotted the four series of azimuths thus obtained, on diagrams of the form referred to, the observer is equipped with charts which will enable him to see at a glance the significance of any solstitial or May-year azimuths he may find in all places of about latitude 37°–38° N.

If the archæological surveyor is not prepared to take the trouble involved in the ordinary method, there is another simpler way of obtaining the solar azimuths in varying latitudes, if he is contented to deal with observations on the horizon merely and therefore to neglect heights of hills. This method consists of using the table of amplitudes given in Chambers' Mathematical Tables (pp. 414 and 415, last edition). This table gives the amplitudes of sun or star rise with declinations between 0° and 23°28′, for latitudes 0° and 66°.

The azimuth $= 90° -$ amplitude.

This table includes the solar declination at the solstices and in May and November, but gives only approximate values because the sun's semi-diameter and the effects of hills and refraction are not taken into account.

The tables may also be used, of course, for any star having a declination lying between 0° and 23°28′, and will give results nearer the truth because there is no semi-diameter correction for a star.

Example.—Find the azimuth of the May-sun in latitude 37°30′ N.

	Amplitude of sun, declination	16° N. in latitude	37° N. ...	20° 11′
	,, ,, ,,	16° N. ,,	38° N. ...	20° 28′
Therefore	,, ,, ,,	16° N. ,,	37° 30′ N. ...	20° 20′
	Amplitude of sun, declination	17° N. in latitude	37° N. ...	21° 28′
	,, ,, ,,	17° N. ,,	38° N. ...	21° 47′
Therefore	,, ,, ,,	17° N. ,,	37° 30′ N. ...	21° 37′

By interpolation, amplitude of sun, declination 16°20′ N., in lat. 37°30′ N., $= 20°46'$, therefore azimuth is $90° - 20°46' = 69°14'$.

The preparation of reconnaissance-charts for star azimuths follows somewhat different lines, because instead of dealing with the sun at definite declinations, we deal with stars each of which has different declinations at different epochs. For example, suppose the observer wishes to investigate possible clock-stars alignments in and at 37°30′ N.

Such a set of curves as those given for Aberdeenshire (lat. 57° N.) on pp. 102–3 will be of use.

For the computation of the values of such curves we must know the latitude, the zenith distance (depending upon the elevation of the horizon), and the declinations. The latitude is known, the elevations of the horizon we assume as 0°, 1°, 2°, and so on, and the declinations are computed as follows. We will construct the curves so that they may be used for any azimuths from N. to N. 45° E.

A star appearing on the horizon due N. is a circumpolar star, just grazing the horizon, that is to say the distance of the star from the pole, less the amount it is apparently lifted by refraction, is equal to the angular distance of the pole from the horizon, which is the same as the latitude of the place, Therefore a star rising in azimuth 0°, in latitude 37°30′ N. has the N.P.D. 37°30′+ 35′ (refraction)=38°5′, that is its declination is 90°−38°5′= 51°55′ N. This is the first point for our curves, being the declination of a star visible in azimuth 0° with a level horizon in lat. 37°30′ N. To find approximately the declination of a star rising in Az. N. 45° E., we employ the formula (3) given on p. 87, or we may get it, roughly, by inspection, from a celestial globe; it works out at about 34° N. Thus for the 0° hill curve our range of declination is from 51°55′ N. to 34° N.

In computing the azimuths it will be quite sufficient to take three or four points on each curve, and as the curve of the bend increases as it approaches azimuth 0°, three of the four points should be taken on, say, that half of the curve. Thus in our range of 51°55′ to 34° where we know the first point (azimuth 0°) we might take the second and third points at declination 47° and declination 42° respectively: the fourth would, of course, be declination 34°.

The method of computation is that shown on p. 72; in each

case the value of c will be $90° - 37°30' = 52°30'$, z will be $90°35'$, and Δ will have the different values ($90° -$ declination assumed).

These calculations furnish us with four azimuths corresponding to the four selected declinations, in lat. 37°30′, and with a level horizon. Similar calculations will give us four sets of related azimuths and declinations for each elevation of the horizon we care to take. In all cases c (co-latitude) will have the same value, but z will be different for each set as shown in the table on p. 106. Δ will vary as before.

Having calculated these azimuths the next step is to plot them on curves as shown on fig. 49, taking the azimuths as abscissæ, the declinations as ordinates, and tracing a separate curve for each elevation of the horizon.

To such a set of curves we may attach the names and corresponding dates of any stars which ever came within our declination range, but, to prevent over-crowding, it is perhaps desirable that only the most probable stars should be connected up at first; others may be attached later if anything resulting from the preliminary work shows it to be desirable that they should be. In the example shown on fig. 49, Arcturus, Capella, and Castor were shown to be the stars most likely to be found in Aberdeenshire and the dates corresponding to the different declinations were determined, by inspection from the declination curves given on p. 99.

In the foregoing cases we have dealt only with curves suitable for a restricted area. For general work it is desirable to have curves covering a large range of latitude, such as are shown in fig. 35, p. 51, where the relation between declination and azimuth is shown over a latitude range 49° to 59° N. The method of preparation is, in general, the same as that we have just described but, in order not to complicate the diagram unduly, only the curve for a level horizon (0°) should be plotted for each latitude and the latitudes may be taken in 2° steps, *e.g.* 32°, 34°, 36°, and so on.

The azimuths may be taken from tables or calculated by the simple formula $\cos A = \cos \Delta \cos \lambda$ as before.

If general curves be required for each of the solar alignments, such as those shown on pp. 76–79, the method of procedure is again similar. The formula given on p. 72 is employed.

2. *The Study of Plans.*

The foregoing suggestions apply when the observer is preparing to measure the azimuths of the alignments in the field, but there is another method of investigation which may be employed even when field observations are impracticable. This consists in the study of carefully prepared plans which show the directions of the alignments referred to the meridian.

There exists a large number of plans, prepared by surveyors, of monuments, in various countries, which should afford plenty of material for discussion. But there is frequently a serious barrier to the intelligent discussion of such plans; sometimes no statement is made as to whether the N.-S. line represents the astronomical or the magnetic meridian. It not infrequently happens that they are not oriented at all; in this case the plans are, of course, absolutely useless from the orientation point of view.

The hopeless absurdity of publishing plans, probably resulting from *magnetic* surveys, with no statement as to the meaning of the N.-S. arrow is, far too often, very forcibly impressed upon the astronomical investigator of ancient monuments. Great care must be exercised, therefore, when using published plans to see that there is no ambiguity on this point. A large number of instances could be quoted where the whole meaning of the monument has been entirely distorted by the uncertainty, or error, resulting from the study of such incompletely, or erroneously, oriented plans.

If no uncertainty exists as to the orientation, such plans afford an immense opportunity for useful and fruitful work. The *relative* directions of the sight lines are, in most cases, shown with minute accuracy, for it is not at all a difficult matter to survey a monument, it is quite a different story to orient the plan accurately.

Presuming that the orientation is stated definitely to be magnetic, there is little difficulty in finding the true north and south line *if the date of the survey is known.* This being given, reference to the Admiralty Charts of the surrounding sea, at about the date, correcting for the annual change of the variation which is always given, will show the magnetic variation which must be employed as a correction to the magnetic values given on the plan.

Having determined our true N. and S. line, the solution of the alignment problems presented on a map or plan is a comparatively simple matter.

Draw a series of lines across the plan, parallel to the N.–S. line so that each alignment is cut by, or may be produced to meet, one of them.

With a good protractor measure the angles thus made with the meridian and mark each angle, either with its value in degrees or by a reference letter. This procedure gives us two angles, one to the E. the other to the W., for each intersection and we have to decide which of the two shall be considered. There are many criteria.

In some cases, for example that of a temple with one end closed, as in the normal case, the plan will show at once that observations were possible only in the one direction.

Again if the alignment is either a high north-easterly or a low south-westerly one we decide, from previous experience, that it is in all probability a clock-star alignment with which we are dealing and, further, that such observations were usually made at star-rise; consequently we take the N.E. direction. If we meet with a line which may either be taken as a little north of east or a little south of west, we have learned that whilst the Pleiades, used as a warning for the May sun rose a little north of east, there was no corresponding warning star setting a little to the south of west; therefore we take the line to the east, as a possible alignment to the heliacal rising of the Pleiades. In a similar manner reference to the various solar-azimuth curves will often decide this question in the case of a solar alignment.

Having measured the angles made with the meridian by the various alignments, it is necessary to reduce these azimuths to declinations before we can finally determine the nature of the alignment or its date. This can be done, in a reconnaissance, by reference to curves similar to those given on p. 51, or in the case of alignments lying within the solar limits, to the tables.

If the specific curves or tables are not available we must employ some general method of reduction. If the declinations are probably less than 23°30′ N. or S. we may use Chambers's tables, but if

they lie outside these limits recourse must be had to the usual methods of computation.

a. To deal with stars within Chambers's limits. In a known latitude. Convert the measured azimuths to amplitudes by subtracting the value from 90°, e.g. azimuth N. 68°28′ E. = 90° − 68°28′ = E. 21°32° N. amplitude, latitude 40°.

Turning to pp. 414—415 of Chambers's tables, we find "latitude" given in the first vertical column, and in each horizontal row of figures opposite is given the corresponding amplitudes. For example, finding latitude 40° in the first column we pass along the amplitude values in the horizontal row of figures until we find 21°32′; the nearest value is 21°5′ = 16° declination. The next value is 22°26′ = 17° declination, and, interpolating, we find that amplitude E. 21°32′ N. in latitude 40° N. corresponds to declination 16°20′ N. On referring to the Nautical, or to Whitaker's Almanac we see that this is the sun's declination on May 6, therefore the alignment we are dealing with is to the May sun.

Taking another case, suppose we have found an azimuth N. 78° 53′ E. i.e. 90° − 78° 53′ = E. 11°7′ N. amplitude. The nearest values to this given in the tables opposite lat. 40° are 10°28′ and 11°47′ corresponding to 8° and 9° declination respectively. Again interpolating, we find that 11°7′ corresponds to declination 8°30 and as our amplitude is N. this declination is 8°30′ N. An inspection of the stellar declination curves given on p. 99 shows that this declination would fit *a* Tauri (350 B.C.). The Pleiades (1400 B.C.), or *a* Virginis (1600 B.C.).

Of these we know from previous results that both the Pleiades and *a* Virginis (Spica) were employed by the temple builders as warning stars, the former as a warner of the May-sun the latter as a warner of the equinoctial sun.. Where there is more than one star collateral evidence often gives the clue as to the one employed. For example in this case we know that the Pleiades were most generally employed.

b. We will now consider the case of such alignments as lie outside the limits given in Chambers's tables. Assuming the zenith distance, for the preliminary investigation, as 90°0′, i.e. a hill of ½° counteracting refraction, the declination may be calculated by the formula and method given on p. 87.

INDEX AND GLOSSARY

1 *

INDEX

INCLUDING A GLOSSARY OF THE TERMS USED

THE END

R. CLAY AND SONS, LTD., BREAD ST. HILL, E.C., AND BUNGAY, SUFFOLK.